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REPORT

STUDY OF THE SAVINGS ACHIEVED

BY

HIGHER EFFICIENCY GAS FURNACES AND BOILERS

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SUMMARY

Recent development of higher-efficiency gas-fired furnaces and boilers for residential space heating has substantially increased the options available in both the new and replacement heating system markets. Although a few years of field experience have been accumulated, a clear picture of what this new technology may mean to the consumer and the energy utilities has not yet emerged. In order to be able to inform the public more fully about expected energy savings and other aspects of the new furnaces and boilers, complementing information transfer services already being provided on other facets of residential energy conservation, Manitoba Energy and Mines and Energy, Mines and Resources Canada jointly undertook the current project.

This report comprises the results of an investigation of the field performance of replacement standard and higher-efficiency residential gas furnaces and boilers in Manitoba, including both an examination of changes in energy consumption and a survey of homeowner experiences with the installation and the operation of the new units. A third component of the project, with this report as a basis, is the dissemination of the knowledge gained from the study to industry and trade persons and the general public.

A group of 326 replies from 983 surveyed homes which had new higher-efficiency furnaces and boilers installed between September 1985 and August 1986 provided a good sample for analysis, complemented by the 89 responses received from 294 homes surveyed as part of a supplementary study of standard furnace and boiler replacements. A wide distribution of older and newer houses of commonly built styles were represented. Various lifestyles were represented in the sample, with the most common reply coming from a 1950's or 1960's bungalow whose current owners had been its only occupants, and whose family size was now trending lower.

Breakdown or perceived risk of breakdown was the main reason for replacement of the old heating plant in almost two-thirds of the higher-efficiency sample houses, with actual failure occurring in 39 percent of the cases, usually due to heat exchanger cracking or corrosion. Where the replacements were standard furnaces or boilers, the old units had failed in 70 percent of the cases. About two-thirds of the replaced units were between 20 and 30 years old.

Advice provided by the heating contractor was the reason most commonly cited for the homeowners' choice of particular make and model of replacement furnace or boiler. One to three quotations were typically obtained before final selection, with there being a greater tendency toward one quotation if the replacement heating plant was a standard unit. In the case of higher-efficiency replacements, there was slightly more reliance upon the heating contractor and the number of quotations obtained was slightly smaller if the old unit had failed.

Less than two percent of all respondents reported a decrease in comfort level with the new higher-efficiency heating systems. Of the remainder, those who felt that their homes were more comfortable slightly outnumbered those who thought that comfort had not been changed, and a comfort improvement was more common in the case of high-efficiency furnaces, in older houses, and in smaller houses. Those who reported a comfort improvement also tended to report a lowering of effective thermostat settings which, at more than 1 degree Celsius on a group-wide basis, was more than double the reduction reported by the comfort-unchanged group.

For new standard heating systems, the proportion of survey respondents reporting reduced comfort was about five percent, while 58 percent felt there had been no change. Average reported effective thermostat setting was about 0.5 degree Celsius lower with the new unit where comfort was thought to have improved. If comfort was considered to have been unchanged by the new furnace or boiler, the average reported setting with the new unit was about 0.25 degree lower.

Thirty-four percent of the homeowners reported having experienced a problem requiring one or more visits by the heating contractor or service-person between the time of installation and the time of completing the study questionnaire. Where non-routine service visits did occur, 16 percent involved an expense to the homeowner. The corresponding figures for the standard replacement group were 25 percent receiving non-routine service visits, and 12 percent incurring an expense. The range of repair costs reported was lower in the case of the standard equipment.

Energy-savings analysis was completed on a total of 194 homes in which the heating system replacements were the only changes significantly affecting heating energy consumption. Fuel usage reductions were determined for a normalized weather year by characterizing the heating fuel usage rates for each house on the basis of actual meter readings made between 1982 and 1988. The range of natural gas savings achieved in the final sample of project houses was found to be quite broad for each furnace and boiler type, and individual results were well distributed within the ranges.

In particular, the 66 homes with gas domestic water heaters and new mid-efficiency (induced draft) furnaces saved between 2 and 29 percent on the total annual gas consumption. The average saving was 15.8 percent. Corresponding results for the estimated space heating portion of the total gas consumption were a range of 3 to 34 percent savings and an average saving of 19.2 percent. For a small subsample of 11 houses with electric domestic water heaters and mid-efficiency furnaces, the average gas usage reduction was 20.5 percent.

For high-efficiency (condensing) furnaces in 49 houses with gas domestic water heaters, the range of savings on total gas consumption was 17 to 37 percent, with an average of 27.5 percent, and the corresponding results for the estimated space heating portion were a range of 19 to 49 percent, and an average of 34.0 percent. In a small subsample of 5 homes with electric domestic water heaters and high-efficiency furnaces an average reduction in gas consumption of 31.5 percent was achieved.

The savings in a group of 14 gas-DHW houses whose replacement furnaces were upgraded conventional models (naturally aspirated furnaces fitted with automatic flue dampers and intermittent pilots) averaged 6.9 per cent on total gas consumption, and 8.5 per cent on the estimated space heating portion.

The change in gas consumption in 38 houses in which an old standard furnace was simply replaced with a new one averaged close to zero, with a range from an increase of 13 percent to a decrease of 17 percent.

In small subgroups of houses with hot water heating systems, the average gas savings on total consumption were 10.5 per cent and 15.2 per cent for upgraded conventional and high-efficiency replacement boilers, respectively. On the estimated space heating portion only, the corresponding average savings were 12.9 and 18.1 per cent. There was little change in gas consumption in houses where the replacement boiler was a standard unit.

Variations in savings attributable to house type, era of construction, old furnace type, change in comfort/thermostat settings, and several installation and operating differences were found to be minor compared to the overall scatter of the results. It is possible that differences in the operating performance of the units which were replaced may have contributed in large part to the ranges of results that occurred. The retention of an open draft hood for a gas domestic water heater in most of the houses may also have had a significant effect on the overall fuel savings.

In light of the wide ranges of percentage savings which occurred in groups of actual Manitoba installations of standard and higher-efficiency furnaces and boilers, and the lack of a complete understanding of the reasons for these ranges, the following recommendations were made:

(a) The consumer, governments and building officials, and the heating industry should be made aware of the ranges of savings which occur when higher-efficiency furnaces and boilers are installed as replacements.

(b) Consistent means of reporting the performance characteristics of heating equipment, respecting the consumer's needs, should be devised and adhered to by the heating industry, governments, and other officials.

(c) A greater ability to determine and predict heating system performance in the field should be acquired, leading to a more complete perspective of the benefits of standard and higher-efficiency equipment.

ACKNOWLEDGMENTS

Many people willingly provided assistance during completion of this study. Their contributions are greatly appreciated. In particular, distributors and installers of heating equipment in the Winnipeg area provided us with information on their products and answers to questions about installation and operation. The Manitoba Department of Labour's record of gas permits allowed us to locate the sample of recently installed higher-efficiency furnaces and boilers. The three utilities, ICG/Greater Winnipeg Gas, Winnipeg Hydro and Manitoba Hydro, helped us to find the meter reading records upon which the analysis depended. Finally, we would especially like to thank all the homeowners who shared their experiences. Hopefully our findings will be useful to the various groups.

TABLE OF CONTENTS

Section		Page
1	INTRODUCTION	1
2	BACKGROUND	2
3	HIGHER-EFFICIENCY FURNACES AND BOILERS	4
4	METHODOLOGY	6
	4.1 SAMPLE SELECTION	6
	4.2 ANALYSIS OF ENERGY CONSUMPTION	8
5	THE SAMPLE	13
	5.1 VALIDITY OF SAMPLE	13
	5.2 FURNACE AND BOILER TYPES REPRESENTED IN THE SAMPLE	13
	5.3 HOUSE PROFILE	14
	5.4 OCCUPANT PROFILE	14
	5.5 GAS USAGE CHARACTERISTICS	14
6	ENERGY SAVINGS ANALYSIS	18
	6.1 DOMESTIC WATER HEATING	18
	6.2 GAS SAVINGS	18
	6.3 VARIABILITY OF THE ENERGY SAVINGS	19
	6.3.1 House Characteristics	19
	6.3.2 Old Furnace Type	19
	6.3.3 Comfort Change and Thermostat Settings	20
	6.3.4 Other Changes to the Heating System	20
	6.3.5 New Furnace or Boiler Model	21
	6.3.6 Other Factors	21
7	HOMEOWNER EXPERIENCES	32
	7.1 REASONS FOR REPLACEMENT	32
	7.2 SELECTION CRITERIA	32
	7.3 SERVICE AND REPAIRS	33
8	CONCLUSIONS	41
9	RECOMMENDATIONS	43
	REFERENCES	45
APPENDIX A	QUESTIONNAIRE	
APPENDIX B	COMFORT LEVELS AND HIGHER-EFFICIENCY GAS HEATING SYSTEMS	
APPENDIX C	SUPPLEMENTARY STUDY OF REPLACEMENT CONVENTIONAL FURNACES AND BOILERS	

LIST OF FIGURES

Figure		Page
4.1	CHARACTERIZATION OF HEATING FUEL USAGE FROM METER READINGS	11
4.2	MONTHLY AVERAGE NORMALIZED HEATING FUEL USAGE RATES	12
4.3	ELECTRICITY USAGE RATE HISTORY	12
5.1	COMPOSITION OF STUDY HOUSE SAMPLE	16
5.2	STUDY HOUSE SAMPLE CHARACTERISTICS: LENGTH OF OCCUPANCY	17
5.3	HEATING FUEL USAGE CHARACTERISTICS OF STUDY HOUSE SAMPLE	17
6.1	ESTIMATED ANNUAL NATURAL GAS CONSUMPTION BY DOMESTIC WATER HEATERS IN 127 STUDY HOMES	23
6.2	EFFECT OF MID-EFFICIENCY FURNACES ON ANNUAL NATURAL GAS USAGE	25
6.3	EFFECT OF HIGH-EFFICIENCY FURNACES ON ANNUAL NATURAL GAS USAGE	26
6.4	EFFECT OF HOUSE TYPE ON FUEL SAVINGS WITH MID- AND HIGH-EFFICIENCY FURNACES	27
6.5	EFFECT OF HOUSE AGE ON FUEL SAVINGS WITH MID- AND HIGH-EFFICIENCY FURNACES	28
6.6	EFFECT OF EXISTING FURNACE TYPE ON FUEL SAVINGS WITH MID- AND HIGH-EFFICIENCY FURNACES	29
6.7	EFFECT OF COMFORT CHANGE ON FUEL SAVINGS WITH MID- AND HIGH-EFFICIENCY FURNACES	30
6.8	EFFECT OF OTHER CHANGES ON FUEL SAVINGS WITH MID- AND HIGH-EFFICIENCY FURNACES	31
7.1	REASONS FOR FURNACE OR BOILER REPLACEMENT	34
7.2	TYPES AND AGES OF REPLACED HEATING PLANTS	35
7.3	NUMBER OF QUOTATIONS OBTAINED PRIOR TO SELECTION OF NEW FURNACE OR BOILER	36
7.4	REASONS FOR CHOICE OF MAKE AND MODEL	37

LIST OF FIGURES (continued)

Figure		Page
7.5	DISTRIBUTION OF NON-ROUTINE SERVICE VISITS	39
7.6	REPORTED PROBLEMS INVOLVING EXPENSE	39
7.7	TYPES OF PROBLEMS NOTED BY HOMEOWNERS WHO RECEIVED NON-ROUTINE SERVICE VISITS	40
B.1	IMPACT OF MID- AND HIGH-EFFICIENCY FORCED AIR FURNACES ON COMFORT LEVELS AND REPORTED NORMAL THERMOSTAT SETTINGS	B.5
B.2	IMPACT OF MID- AND HIGH-EFFICIENCY FORCED AIR FURNACES ON COMFORT LEVELS AND AVERAGE CHANGES IN NET REPORTED THERMOSTAT SETTINGS	B.5

LIST OF TABLES

Table		Page
5.1	DISTRIBUTION OF FURNACE AND BOILER TYPES IN THE STUDY SAMPLE	15
6.1	FUEL SAVINGS SUMMARY - HIGHER-EFFICIENCY SPACE HEATING EQUIPMENT	24
B.1	REPORTED CHANGE IN COMFORT LEVEL DUE TO NEW FURNACE OR BOILER	B.4

Section 1

INTRODUCTION

Recent development of higher-efficiency gas-fired furnaces and boilers for residential space heating has substantially increased the options available in both the new and replacement heating system markets. Although a few years of field experience with the new furnace and boiler technology has been accumulated, a clear picture of what it may mean to the consumer and the energy utilities has not yet emerged. In fact, it will probably be some time before long-term performance, reliability, and impact of the equipment on the house and its operation can be fully understood.

A search of the literature reveals that only a limited number of investigations of higher-efficiency gas heating systems in colder climates have been reported upon. Typically, such studies have consisted of the short-term monitoring of the energy consumption of a small number of furnaces (e.g., References 1 to 8). Surveys of researchers, the residential heating industry, and homeowners have also provided an initial impression of the areas of concern with the higher-efficiency gas furnace (References 9 and 10), and of the heating cost reductions for conversions from oil to high-efficiency gas furnaces (Reference 10). Meanwhile, a variety of research on technical aspects such as exhaust venting, corrosion protection, and process simulation is being carried out (e.g., References 9, 11, 12, and refs. therein).

In order to formulate realistic statements about outcomes to be expected in typical installations of the new equipment, i.e., information complementary to that which is already disseminated on other aspects of residential energy conservation, Manitoba Energy and Mines (E&M) and Energy, Mines and Resources Canada (EMR) jointly commissioned an investigation of higher-efficiency furnaces and boilers. The specific objectives of the project were:

(a) to document the changes in energy consumption for space heating in a large sample of Manitoba homes which have had gas furnaces or boilers replaced with higher-efficiency units;

(b) to profile homeowner experiences with the selection, installation, and operation of the new higher-efficiency furnaces and boilers;

(c) to transfer the knowledge gained from the study to industry and trade persons and to the general public.

The study and its findings are described herein.

Section 2

BACKGROUND

Currently more than three-quarters of the 260,000 forced-air furnaces and 49,000 hot-water or steam boilers in Manitoba consume natural gas or propane (Reference 13). These heating plants include:

(a) a large number of conventional, naturally aspirated, standing-pilot, gas-fired furnaces on the order of 25 or 30 years old;

(b) a large number of originally oil- or solid-fuel-fired furnaces and boilers from 25 to 75 years old or older which have, at some time in the last 25 or 30 years, been fitted with gas-burning inserts;

(c) a third and larger subgroup of conventional forced-air gas furnaces ranging from new to about 25 years old; and

(d) a very small number of conventional, naturally aspirated, standing-pilot, gas-fired boilers which range from new to about 25 years old.

The new generation of higher-efficiency, gas-fired furnaces and boilers which has appeared in the last five years or so has potentially a wide application, both in a replacement market that is apparently ripening with the aging of units installed when gas first became available (i.e., the first group, above), and in new house construction. Just how many replacement furnaces and boilers will be required in the next few years in Manitoba is difficult to forecast because of diverse factors not easily quantified at the present time, such as:

(a) the uncertain remaining lifespan of units which will only be replaced when they fail, and

(b) the ever-changing social and economic variables which can provide motivation for replacement prior to failure.

The new-home market currently accounts for four to six thousand heating systems annually in Manitoba, and the present replacement market is probably at least as large.

Given the foregoing, there may be a very large potential for energy conservation in the residential sector provided that manufacturers' claims of improved energy conversion efficiencies can be consistently translated into gas usage reductions in the field.

The performance of the new equipment is only one of the factors controlling the amount of energy saved. Ultimately, the effect of any change in the heating system will be the outcome resulting from the interactions among the old and new heating systems, the building's physical characteristics, and its occupants. Conversion efficiency, economy, comfort, and other factors may all contribute to that outcome. Energy savings achieved with use of the new higher-efficiency furnaces or boilers are therefore likely to be variable from house to house.

Performance is also likely to vary from region to region due to the interaction of climates with the unique past and present housing styles and construction practices within a region, and due to the ways in which occupants in different parts of the country respond to changes in the resulting interior environments.

In this project, a large number of Manitoba cases were examined, characterizing the experience in that province. The results obtained in the study may be considered to be representative of the initial performance to be expected from a larger group of installations. As well, they provide a realistic view of the ranges of performance to be expected in individual cases. More operating experience will have to be accumulated, however, before full life-cycle performance can be evaluated.

Section 3

HIGHER-EFFICIENCY FURNACES AND BOILERS

Conventional gas-fired forced air furnaces and hot water or steam boilers have retained, more or less, the same reliable technology for decades. A continuous pilot flame is used to ignite the gas delivered through a main gas valve when the thermostat calls for heat. Air for the combustion process and to provide the natural draft necessary for safe evacuation of combustion products is supplied from the outdoors through cracks and openings in the building envelope.

Initial attempts to refine this process focussed on:

(a) the uncontrolled and excessive flow of heated indoor air to outdoors through the chimney or B-vent, particularly during the portion of the heating cycle when combustion was not taking place, and

(b) the quantity of fuel consumed by the stand-by pilot.

During the 1970's and early 1980's, first-generation solutions to these problems reached the mainstream market. To counter the air-loss problem, an electrically activated mechanical damper was positioned in the flue downstream of the standard draft diverter or hood. It was intended to be open only when draft was required. To eliminate the stand-by gas consumption, provision was made for the pilot flame to be normally extinguished, and to be first ignited with an electrical spark and then proved prior to the opening of the main gas valve. In Manitoba, many new furnaces and boilers fitted with automatic vent dampers and intermittent pilots were installed up to the mid-1980's.

Over the years a reputation for unreliability grew up around the new features, as there were many failures which generated service calls and parts replacements. However, a realistic perspective of this issue is difficult to establish in the shadow of the exemplary performance record of the conventional gas heating technology. It did become apparent, though, that the vent-damper approach did not completely curtail air flows up the chimney in houses where other fuel-fired appliances with draft hoods were operating (e.g., the domestic water tank/heater). At present the availability of, and the market for, these options on otherwise conventional furnaces and boilers is quite limited.

The newer generation of higher-efficiency furnaces and boilers is fundamentally different from the conventional technology. In addition to the electronic ignition systems and improved heat exchange mechanisms which are common to all of the current medium- and high-efficiency units, power-venting with an exhaust-gas fan or by other means is used to induce both draft and combustion air. There is little exhaust air flow during the off-cycle. Many of the makes and models currently available can be vented laterally through a side wall of the house. However, the problem of vent losses through other conventional combustion appliances connected to a chimney remains unresolved.

To complement the conventional, standing-pilot furnaces and boilers, which may have seasonal energy-conversion efficiencies in the 55 to 70 percent range and flue gas temperatures of 230 degrees Celsius (C) or more, the higher-efficiency units offered by manufacturers in 1988 may be categorized into the following two groups:

(a) mid-efficiency induced draft types: flue gas temperatures reduced to approximately 150 to 180 degrees and seasonal efficiencies of near 80 percent, and

(b) high-efficiency condensing types: flue gas temperatures reduced to about 40 to 60 degrees, condensation of water vapour from the exhaust gases, and seasonal efficiencies ranging from about 87 to 97 percent.

Forced air furnaces and hot water boilers of the above two groups were the focus of this project, although, for purposes of comparison, the conventional unit upgraded with automatic vent damper and intermittent pilot was also examined.

Section 4

METHODOLOGY

4.1 SAMPLE SELECTION

Gas permit records maintained by the Manitoba Department of Labour were used to identify 983 Winnipeg-area homes in which natural gas furnaces or boilers were replaced with higher-efficiency units in the interval between mid-September 1985 and mid-August 1986. This total includes almost all of the induced draft and condensing furnaces and boilers which were installed in the geographical area as replacements during that interval, along with a few of the upgraded conventional units (i.e., intermittent gas pilot systems and electro-mechanical automatic vent dampers) which were installed during the same period. In the group, 29 cases represented installations of new boilers and the other 954 were furnace installations.

The time interval for replacement was chosen to provide a sufficiently long period for post-replacement gas consumption analysis, while still minimizing consideration of superceded technology so that study results would apply to those models available in 1988 and likely to be in production for some time.

The sample was restricted to installations in and around Winnipeg in order to facilitate possible site visits during the project. Investigation was also restricted to natural gas because of the much longer records necessary for valid assessment of bulk propane usage rates.

A brief questionnaire was sent to the 983 homeowners in the sample. In it, they were asked to assist in the study by providing details and dates about their houses, heating systems and lifestyles both before and after their furnaces or boilers were replaced. Also requested, via a consent form to be signed and returned, was their permission allowing the respective utilities, ICG/Greater Winnipeg Gas Company, Winnipeg Hydro, and Manitoba Hydro, to release meter reading records for analysis of energy consumption patterns. The package sent to the homeowners is included as Appendix A.

Adequately completed questionnaires were received from 338 homeowners, representing 328 furnaces and 10 boilers. Follow-up calls were made to about 20 percent of the respondents to clarify some of their answers and to obtain further information. Twelve of the 338 cases represented uncommon situations, such as conversions from oil to gas or from hot-water to forced-air systems, and these were eventually excluded from further study.

The remaining 326 cases (317 furnaces, 9 boilers) were each examined to determine if they were suitable for a comparison of the natural gas usage before and after replacement of the old naturally aspirated, standing-pilot type of furnace or boiler. Criteria included at least one year of operation with the new furnace or boiler and one to five years of operation with the old unit, subject to:

(a) occupancy of the house by the same family for the entire period of the analysis,

(b) insignificant change in the nature of occupancy over the period due to changes in number of occupants, such as may have been effected with the addition of infant children or the departure of older children,

(c) insignificant use of other explicit sources of space heating energy, such as wood-burning appliances and electrical resistance heaters,

(d) insignificant changes in usage patterns for all non-explicit heat sources such as solar gains, waste heat from interior use of electrical appliances and fixtures and from the very few secondary natural gas appliances which were encountered in the group,

(e) steady inferred pattern of domestic hot water usage, whether provided through use of electricity or natural gas,

(f) no usage of common-metered natural gas for space or water heating outside the confines of the primary dwelling (e.g., swimming pools and garages),

(g) no changes in the dimensions of the heated space,

(h) no changes in the thermal resistance of major building envelope components through addition or deletion of insulating materials,

(i) insignificant changes in windows and doors,

(j) insignificant changes in the resistance of the building envelope to uncontrolled air infiltration and exfiltration, and

(k) insignificant changes in net fan-forced ventilation rates.

Judgment was applied in the application of the above criteria, most often in deciding the significance to the analysis of a minor change to a house or its operation. It was assumed that the furnace or boiler replacement would have a noticeable effect on gas consumption rates.

The result, defined for each house, was an interval between early 1982 and early 1988 within which the only significant alteration was the replacement of the heating plant. Both pre- and post-retrofit intervals were long enough for energy consumption analysis in 250 of the 326 cases. For 88 of the 250, it was additionally concluded that the minor changes which had been accepted as being "insignificant" in comparison to the effects of a furnace or boiler replacement nevertheless might be detectable in an analysis of energy savings where they were the only changes to the houses. These houses were set aside for later study, if necessary. The remaining 162 houses were selected for actual utility record analysis.

4.2 ANALYSIS OF ENERGY CONSUMPTION

Meter reading histories for the 162 houses were compiled with the assistance of the ICG/Greater Winnipeg Gas Company, Winnipeg Hydro, and Manitoba Hydro. With few exceptions, actual meter readings were taken at two-month intervals, the meter-reading day being dependent on location within each utility's distribution network. For the two energy sources, natural gas and electricity, the meter reading intervals did not normally coincide.

A typical example illustrating the nature of the energy consumption records used in the analysis is shown in Figure 4.1(a). The example house is one of the 162 which were examined. Consumption rates shown in the figure are the averages over the intervals between readings, and are plotted at the midpoints of the intervals.

The characteristically large annual temperature swing of the Manitoba climate makes it a simple matter to evaluate home heating consumption, even with a two-month meter reading interval. In Manitoba, the transitions to summer and winter are abrupt and, except for low-energy/passive solar dwellings, this rapid change of season clearly separates the heating and cooling periods. During the heating season, and where a more or less constant interior thermostat setting is maintained in a house, the outdoor temperature explains almost all of the variation in heating energy usage.

In contrast, during the transition seasons between summer and winter in milder geographical regions, periods of both heating and cooling of the interior space may be experienced within a short interval, and energy contributed from the sun may have a significant impact. Careful separation of the various effects is necessary to an understanding of the behaviour of a house and its use of energy in such an environment.

A comparison of the natural gas consumption rates and mean daily Winnipeg temperatures for the example house of Figure 4.1(a) is shown in Figure 4.1(b). Consumption rates during the heating seasons are very clearly defined by the meter reading-based consumption data. For the non-heating seasons during the period prior to furnace replacement (Dec 1982 - Oct 1985), the base summer consumption represents operation of the domestic water heater plus the old forced-air furnace's standing pilot. With the replacement furnace (Feb 1985 - Dec 1987), the water heater consumption is all that makes up the base summer natural gas usage visible in Figure 4.1(b), because of the electronic ignition system of that furnace.

Best-fitting regression lines (least squares) over the pre- and post-replacement heating seasons, along with a straight line approximation of the behaviour during summer, are superimposed on the raw usage rates in Figure 4.1(b). In this case, the value of R^2 (i.e., the coefficient of determination, or the fraction of variation explained by the linear least squares regression assuming equally weighted points) is greater than 0.98 for both the pre- and post-replacement heating periods. This example represented one of the poorer fits encountered among the 162 house cases which were analyzed. In most cases the minor scatter about the regression line may be attributed to violations of the assumptions, such as fluctuating thermostat settings, variations in hot water usage from one interval to the next, etc.

For most Manitoba houses of conventional construction the temperature correlation/regression approach provides a good representation of the heating consumption rates, and the rapid transition between heating and non-heating seasons limits the non-linear effect of the solar radiation contribution. The heating system either dominates as an energy source, or it is not required and does not operate.

If the house is operated consistently, the linear relationship is characteristic of the net effect of the heating system, the building, and occupancy patterns, and can be used for prediction of gas usage over intervals longer than about a week, as well as for comparison among houses. Predictability is normally within a few percent, given the high degree of correlation usually found. Errors are greater if the relationship is applied to time intervals of a few days or less, mainly due to the fact that a building's full response to rapid variations in temperature may take several days, and also due to short-term deviations from the general mode of operation of the house.

In this project, the average rate of gas consumption over an interval during the heating season is thus taken as

$$\text{Average usage } (m^3/\text{day}) = A - B * \text{Mean Daily Temperature (C)}$$

in which A and B are the Temperature=0 intercept and the slope terms of the straight line, respectively.

During the non-heating season, the straight line has zero slope, and the average rate of gas consumption over an interval is taken as

$$\text{Average non-heating season usage } (m^3/\text{day}) = A'$$

where A' is a constant.

Predictions of natural gas consumption over the meter reading intervals for the example house are also shown in Figure 4.1(a). The coefficients A, B, and A' used for the pre- and post-replacement periods were obtained using the gas meter reading data in the manner indicated above. The same coefficients, when applied along with the 30-year normal mean monthly temperatures for Winnipeg, were then used to produce an estimated normal year's natural gas consumption rate pattern for that house under both the pre- and post-replacement operating conditions. The two patterns for the example house are illustrated in Figure 4.2.

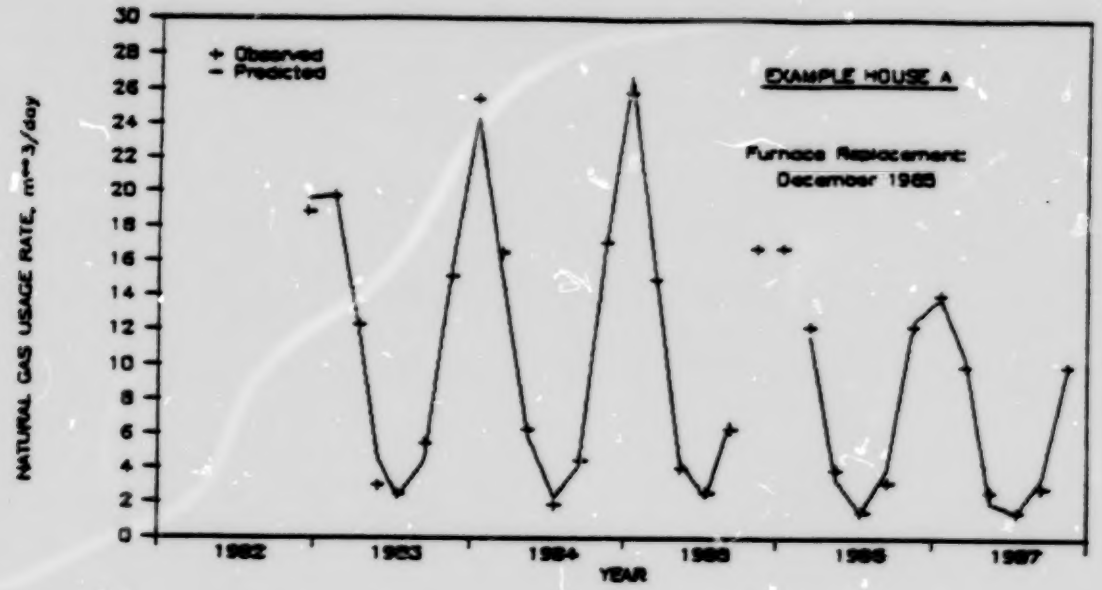
Normalized consumption patterns for all 162 houses were determined in the same way. A few of the houses were found at this stage to be unsuitable for analysis of energy savings because of irregular or anomalous gas consumption behaviour prior to or with the new heating plant, or because of a sparse set of meter readings.

Electricity meter reading records were also examined for each house and those houses with unusual electricity consumption patterns were discarded from the analysis. Unacceptable patterns included usage which was steadily increasing or decreasing or irregularly fluctuating (possibly attributable to changing or unusual occupancy), any of which could be expected to bias the apparent change in furnace or boiler performance.

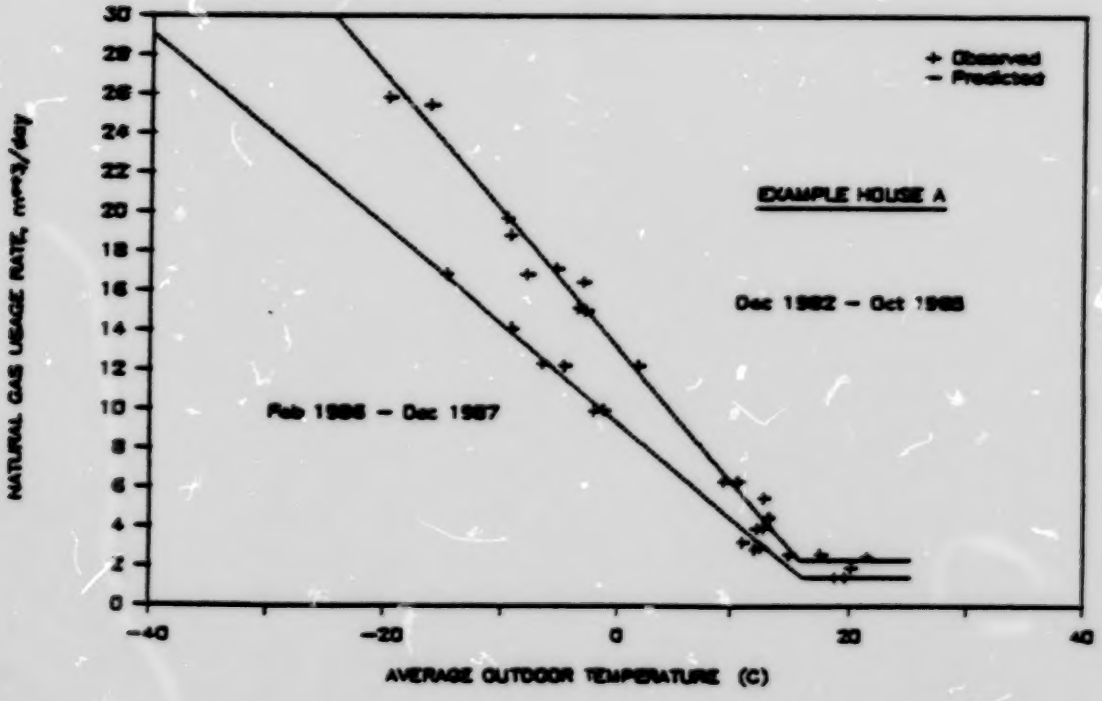
Some sample homes which were outfitted with central air conditioning systems at the time of furnace replacement exhibited subsequent increases in recorded warm-season electricity usage rates. Such houses were retained in the sample unless the increases extended into the heating season.

Other than the above, a number of homes showed a one-time step increase in electricity consumption which coincided with the time of furnace replacement. The example house, referred to above and in Figures 4.1 and 4.2, was one such case. The electricity consumption pattern for that house is illustrated in Figure 4.3. A poll of several similarly affected homeowners indicated that a common element among them was a regime of continuous operation of the new furnace's blower compared with only intermittent operation of the old furnace's blower. All such homes which were in all other ways acceptable for inclusion in the analysis were retained in the sample.

A final group of 144 houses remained following detailed assessment of utility records. This sample included 137 homes with furnaces and 7 with boilers. For each of these, the normal annual natural gas consumptions for the "before" and "after" operating conditions were determined by summing up the totals for the 12 months of the normal year, and the individual and group results were then examined.



(a)



(b)

Figure 4.1 Characterization of Heating Fuel Usage from Meter Readings:
(a) Usage rate history compared with predicted values,
(b) Correlation of usage rates with outdoor air temperatures.

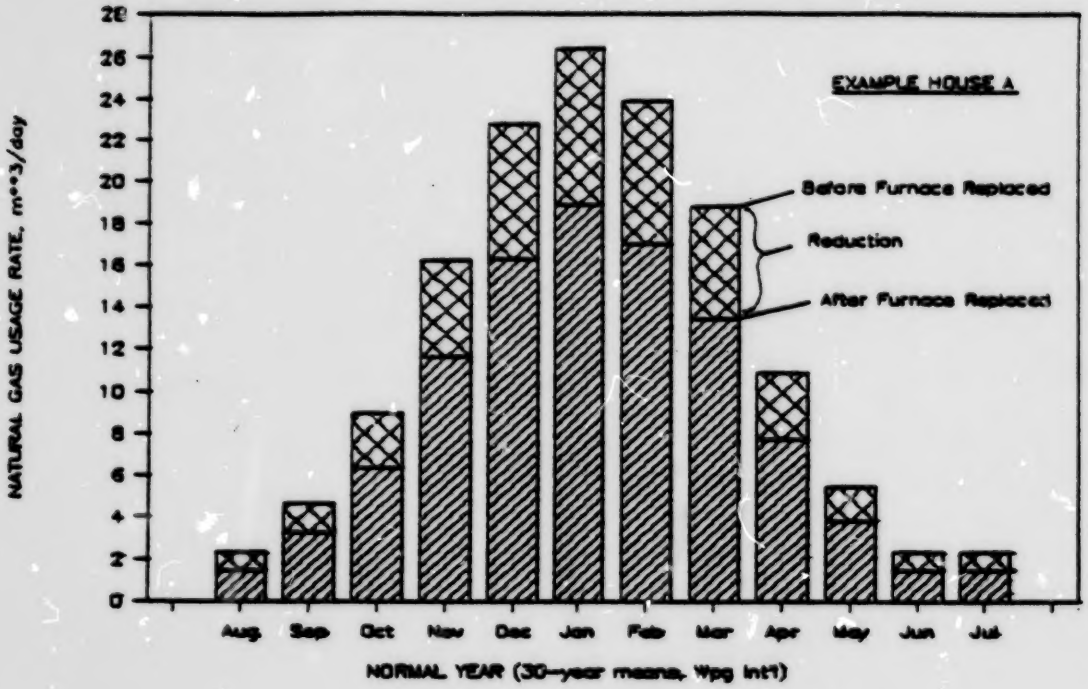


Figure 4.2 Monthly Average Normalized Heating Fuel Usage Rates

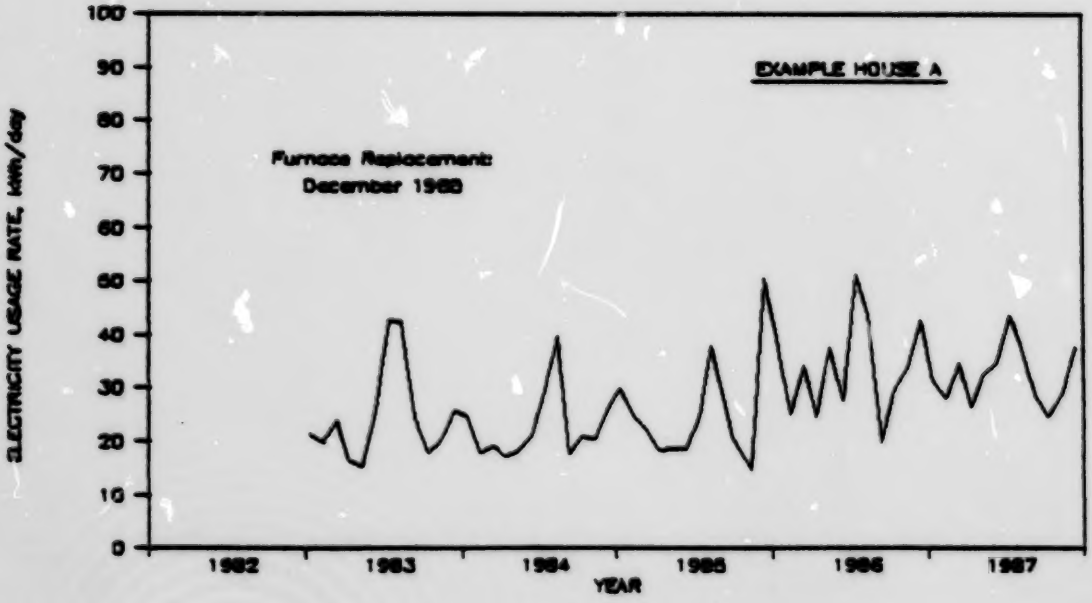


Figure 4.3 Electricity Usage Rate History

Section 5

THE SAMPLE

5.1 VALIDITY OF SAMPLE

The sample of homes generated with the returned questionnaires is "self-selected" rather than "random". It is thus subject to the biases which can affect any poll where participation is voluntary. In this case, the population being sampled was a special group, i.e., those homeowners who, when replacing their older heating plants within a specified interval (September 1985 to August 1986), had chosen to install higher-efficiency equipment. Their responses, detailing experiences with their old and new heating systems, reflect the state of public awareness and the heating industry's experience with the new technology for installations made in the Winnipeg area during that period. It has been a rapidly changing area of technology, so attitudes, understanding, and skills may have changed significantly since then.

From an examination of the completed questionnaires, including both the more provocative experiences as well as those which were unremarkable, and from telephone contact with participating homeowners, the authors' impression is that questions were answered matter-of-factly, that strongly emotional responses were few, and that the sample provides a reasonable distribution for analysis. The sample is profiled below.

The technology itself appears now to have entered an era of minor refinement, with broad industry acceptance of the basic elements to be incorporated into the mid- and high-efficiency furnaces and boilers. Except for minor differences, the units represented in the project sample are the same as those currently available. Further, because manufacturers' ratings for medium- and high-efficiency furnaces and boilers fitted for propane use are almost the same as those for natural gas, the natural gas results reported herein may also be considered to apply to the bulk and metered propane-fired units installed in rural and northern areas.

5.2 FURNACE AND BOILER TYPES REPRESENTED IN THE SAMPLE

The relative proportions of each furnace and boiler type represented in the group which was used for analysis of energy savings are compared, in Table 5.1, to the composition of the larger group of submitted responses, and to the make-up of the original sample from which responses were solicited. The fraction of the homeowners with high-efficiency furnaces who responded to the survey was slightly higher than in the larger original sample. After a program of selection based on technical grounds only (Sections 4.1, 4.2), the proportions of heating plant types shown in the larger samples were essentially maintained.

Within the various furnace and boiler categories in the final sample of 144 analyzed cases, the following manufacturers were represented:

(a) 77 mid-efficiency forced air furnaces: Airco, Carrier, Coleman, Climate Master, Ducmatic Olsen, ICG/Keeprite, Lennox, York

(b) 54 high-efficiency forced air furnaces: Amana, Clare, Coleman, Duomatic Olsen, ICG/Keeprite, Lennox

(c) 6 upgraded conventional forced air furnaces (intermittent pilot and automatic vent damper): Duomatic Olsen, York

(d) 7 higher-efficiency boilers: Slant/Fin, Teledyne Laars, Weil-McLain

5.3 HOUSE PROFILE

Bungalows accounted for nearly two-thirds of the homes in the responding sample. Figure 5.1(a) shows the distribution of house types and ages in the group. The overall proportion of houses in the various age categories is as follows: pre-1945, 21 %; 1945-60, 49 %; 1961-75, 30 %.

House size distribution is indicated in Figure 5.1(b). A majority of the homes are in the 93 to 139 m^2 range (1000-1500 square feet), which refers to nominal area above grade only. Almost all houses in the sample are built over full-depth cast-in-place concrete basements, where the furnace or boiler is located. Some of the larger older houses have stone-and-mortar foundations, and some of the smaller older houses have part (e.g., half or three-quarter) basements.

5.4 OCCUPANT PROFILE

A majority of the responding homeowners have been in their houses for at least 10 years. Length of occupancy is illustrated in Figure 5.2. The responses to the questionnaire indicate that many of the people have been the only occupants of their homes, particularly those moving in between 1945 and 1975. Typically this means the same family was in the house for the entire life of the furnace just now replaced. In general, this also means that children have grown up and the number of occupants in each of these homes is lower than average, often just two. Basements are likely to have been partially or fully developed into bedrooms and/or recreational space and are heated to normal living space temperatures. Responses to the questionnaire also show that any recent upgrading work on these houses tended to be the replacement of windows, doors, and appliances.

Sample homeowners who first occupied their homes in the late 1970's or later tend to be younger, with younger children, and their responses to the questionnaire indicate that, if upgrading work has been done in the last five years or so, it quite likely included improvements to insulation levels.

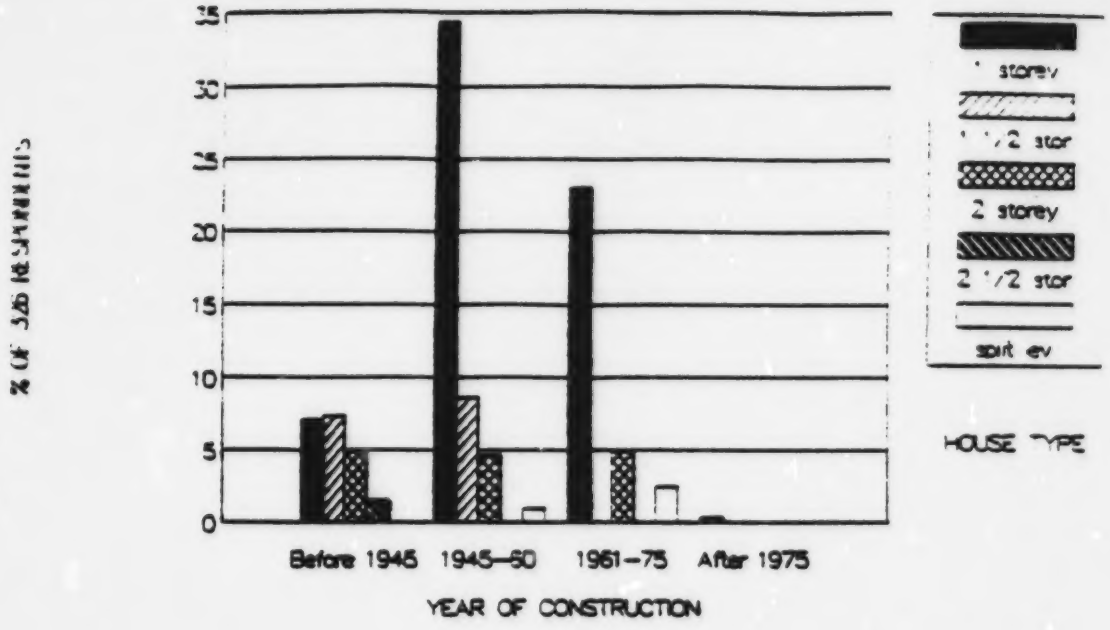
5.5 GAS USAGE CHARACTERISTICS

Normalized natural gas usage totals for the 144-house subgroup for which meter reading analysis was completed are shown in Figure 5.3. The newer houses are relatively tightly clustered, reflecting the uniformity in the housing market in the Winnipeg area from 1945 to 1975. The period saw a gradual increase in average house size, but there was also a slight increase in the overall thermal resistance of the building shell. Bungalows dominated in terms of numbers built. The distribution of gas consumption in the older house group includes the effect of the larger multi-storey homes as well as the very small older dwellings.

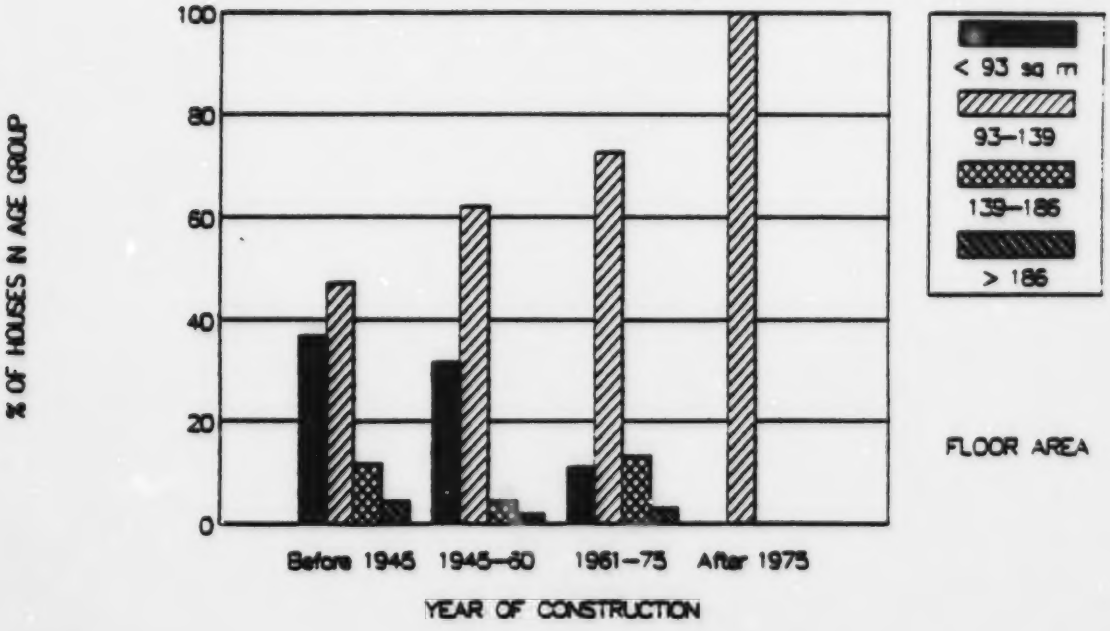
TABLE 5.1 DISTRIBUTION OF FURNACE AND BOILER TYPES IN THE STUDY SAMPLE

Group	No.	% of Total in Group				Comment
		Mid[1]	High[2]	Upgr[3]	Boil[4]	
Surveyed Sample	983	57.3	37.3	2.4	3.0	Questionnaires were mailed to the homeowners
Completed Questionnaires	338	54.4	40.2	2.4	3.0	Approximately 15 additional responses were received too late to be processed, or information was incomplete, or submission was verbal only, etc.
Valid Responses	326	55.2	39.0	2.5	2.8	12 cases were oil-gas conversions, boiler-to-furnace conversions, etc.
Suitable for Analysis	260	55.2	38.8	2.8	3.2	Houses with sufficiently long pre- and post-replacement time periods without other significant changes to house or its operation
Meter Readings Analyzed	162	51.9	39.5	3.7	4.9	Houses in which any changes made within the analysis interval could be considered to have negligible effect on gas consumption
Completed Analysis	144	53.5	37.5	4.2	4.9	In 18 houses, meter readings were sparse or irregular or indicated unusual patterns of gas consumption

[1] Mid-efficiency furnaces
[2] High-efficiency furnaces
[3] Upgraded conventional furnaces
[4] All higher-efficiency boilers



(a)



(b)

Figure 5.1 Composition of Study House Sample:
(a) House age and type, (b) House age and size
(note: 93 m^2 = 1000 square feet, nominal area).

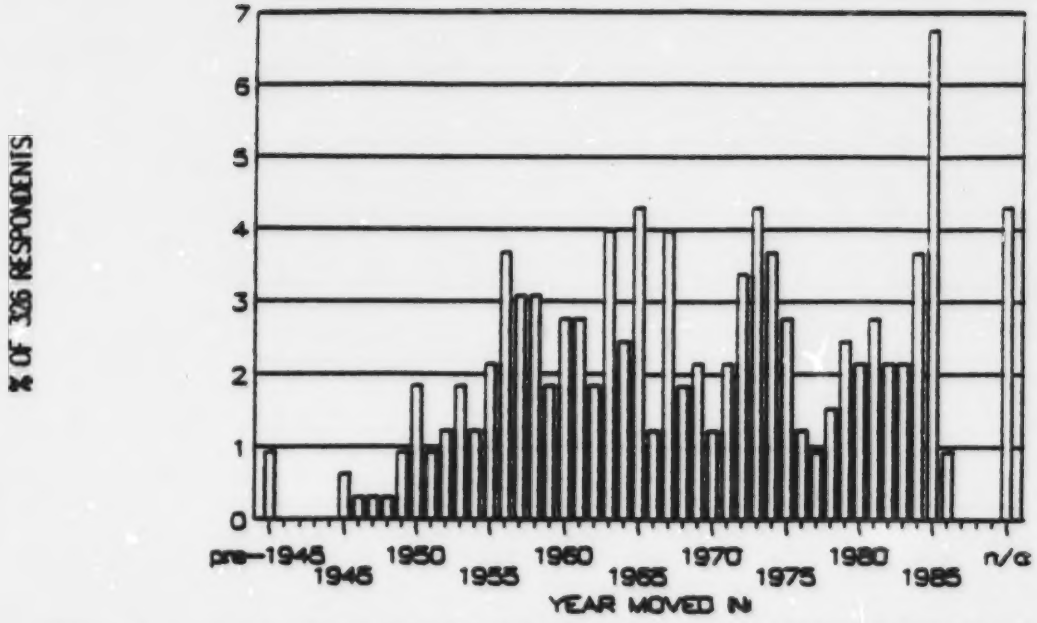


Figure 5.2 Study House Sample Characteristics: Length of Occupancy

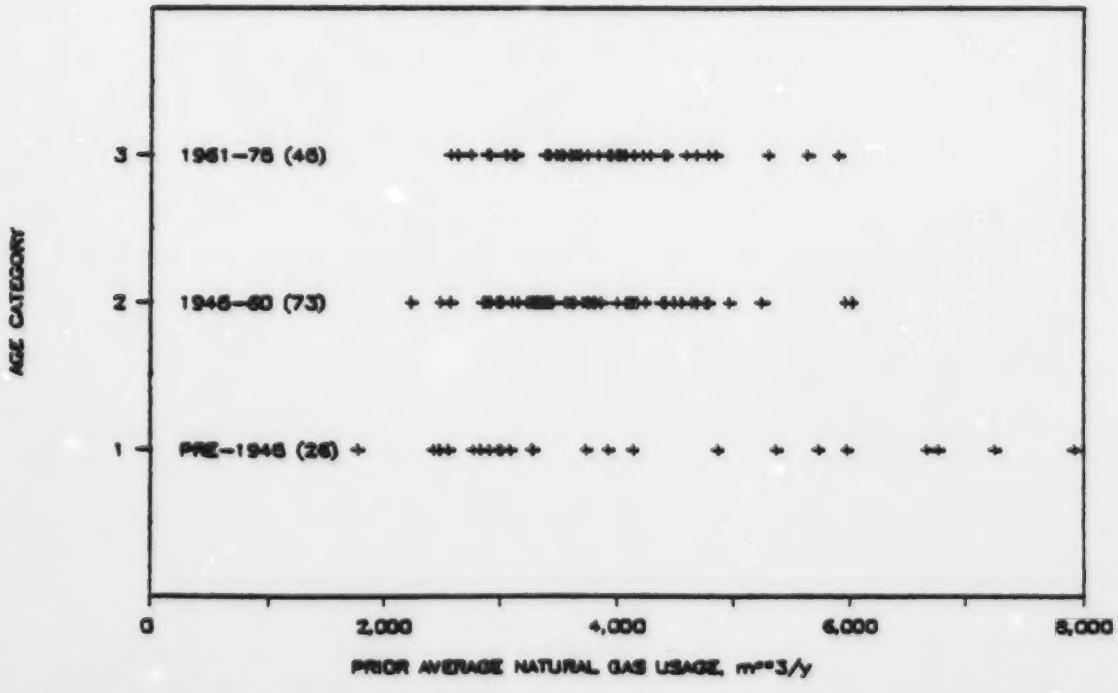


Figure 5.3 Heating Fuel Usage Characteristics of Study House Sample

Section 6

ENERGY SAVINGS ANALYSIS

6.1 DOMESTIC WATER HEATING

A majority of homes in the Winnipeg area, including 85 % of the valid responding sample's 326 homes, have conventional natural gas domestic water heating (DHW) systems. These are naturally aspirated with standing pilots and draft hoods and are vented in common with the naturally aspirated gas furnace.

For the study house group, where replacement mid-efficiency, induced draft furnaces were installed, the usual procedure was to connect to the existing vents with the water heaters unchanged. In some cases (8 %) the chimney was relined. Where high-efficiency condensing-type furnaces were installed, through-the-wall exhausting was incorporated, leaving the water heaters to vent alone into the existing chimneys. Only six of the sample homeowners eliminated the uncontrolled flow of air up the main flue by converting from gas to electric water heating systems. Only four converted from electric to gas. The result of this is a sample dominated by gas water heating systems.

In order to provide an appreciation of the effect of installation of higher-efficiency space heating equipment on the heating portion of the total natural gas usage in sample homes, the domestic hot water portion of the total consumption was approximated. It was assumed for the purposes of analysis that the non-heating season usage rate in the post-replacement period, i.e., the lower curve in Figure 4.1(b), was representative of the water heating requirement over the whole year for the given house and family. Actual usage rates in different seasons would depend on variables such as family activities and inlet water temperatures.

For 127 homes with gas DHW systems in the final analyzed sample of 144, the approximated domestic water heating portions of the total normalized gas consumption are shown in Figure 6.1. The average annual DHW portion thus estimated for this group is 714 m^3. For the same houses the average normalized annual total consumption is 3919 m^3.

6.2 GAS SAVINGS

Fuel savings determined for the various furnace and boiler groups in the study are described in Figures 6.2 and 6.3, and in Table 6.1.

Figures 6.2(a) and 6.3(a) show the effects of new mid- and high-efficiency forced air furnaces on total gas consumption in houses with gas DHW systems. Figures 6.2(b) and 6.3(b) detail the approximated effect on the space heating consumption only, where gas DHW systems were in use, and compare this to those houses with electric DHW systems. Table 6.1 summarizes the results shown in Figures 6.1 and 6.2 for mid- and high-efficiency furnaces as well as the results for hot water boilers and for the upgraded conventional furnaces.

Table 6.1 and Figure 6.2 show, for example, that total gas consumption dropped by an average of 15.8 % in the 66 homes with gas DHW systems and replacement mid-efficiency forced air furnaces. The lowest saving in the group was 2.1 %, and the highest was 28.8 %. Results within the group were distributed such that the range of savings in annual gas usage between which 90 percent of the homes in a similar group would be expected to fall was approximately 5 % to 25 %. When only the space heating portion of the natural gas usage by this group of 66 houses is considered, the mean reduction for the group was 19.2 %, the lowest and highest results were 2.7 and 33.6 %, respectively, and the 90 percent range was 6 to 30 %.

For high-efficiency furnaces with gas DHW systems, Table 6.1 and Figure 6.3 show similarly that the range of savings in the 49 homes was 16.9 % to 37.2 %, with an average of 27.5 %. The 90 percent band of gas savings lay between 18 and 35 %. For space heating gas only, the average estimated saving was 34.0 % for this group, the lowest and highest reductions were 19.3 and 48.8 %, and the 90 percent range was 23 to 45 %.

In most mid- and high-efficiency categories the band of calculated savings is on the order of 20 % wide and well distributed. If such large variations are not merely a characteristic of the group of homes examined in the current project, then they may be expected to be highly important to the consumer who wants to make the right choice about a replacement furnace or boiler. The fact that the ranges are similar for different subgroups of homes and furnace/boiler types is evidence that the results may not be anomalous. Selection of houses for analysis in this study was made with the objective of minimizing the effect of physical and occupancy factors which could cause significant differences in energy consumption patterns (Section 4.1). However, there remain some unaccounted-for features of possible impact. These are discussed below.

6.3 VARIABILITY OF THE ENERGY SAVINGS

Additional factors which may affect fuel savings were examined for their influence on the savings found in the various study houses. This investigation of effects was restricted mainly to the non-sparse mid- and high-efficiency furnace subsamples where the incidence of trends would be more easily discerned.

6.3.1 House Characteristics

House type and age, the normal simple discriminators for use in describing energy-related performance differences among houses, are shown in Figures 6.4 and 6.5 to have a minor effect on the distribution of fuel savings. There may be a tendency for lower reductions in older houses shown in Figure 6.5, but the ranges overlap almost completely for all categories.

6.3.2 Old Furnace Type

Similarly, the comparison, in Figure 6.6, of savings generated when converting to higher-efficiency furnaces from gas-fired units of various types also indicates a slight trend, but does not itself explain the range of results. The tendency to lower savings for the old oil burners retrofitted to run on natural gas is consistent with a general industry understanding

that seasonal efficiencies for such units are slightly higher than those for standard gas furnaces. It should be noted, however, that the presence of an original-oil or original-gas furnace in a house is somewhat dependent on the type and age of house.

6.3.3 Comfort Change and Thermostat Settings

The relationship between the perceived comfort with the new heating plants and the thermostat settings adopted by people in response to their altered interior environments is discussed in Appendix B. Of interest is a possible trade-off of benefits between energy savings and improved comfort in some houses. Older, drafty, poorly insulated homes may be more susceptible to this effect because, for example, lower expenditures for energy may allow higher interior temperature settings, improved heating system effectiveness may warm previously cool spaces, etc.

It was determined from questionnaire responses that the better part of one degree Celsius was the effective difference in thermostat adjustments between houses whose occupants did not report a change in comfort and those who did find the new furnaces had made their homes more comfortable. "More comfortable" tended to mean a greater reduction in thermostat settings. The effect of comfort on fuel savings is shown in Figure 6.7. Again, the range of results appears to be much stronger than the comfort factor.

Reported differences in thermostat settings with the new and old furnaces and boilers ranged from several degrees higher to several degrees lower, with group averages as shown in Appendix B. When the changes in net effective thermostat settings are compared to the gas savings for the houses, no trends are evident.

Real reductions in interior temperature should add to the energy savings generated by the improved energy conversion efficiency of the new furnace. A real difference of one degree would affect annual heating requirements by a few percent for most houses in Manitoba. Several degrees of actual change therefore could have impact of the same order of magnitude as the ranges of fuel savings under discussion herein. However, there could be a counter-balancing effect between, for example, higher temperature gradients (and thus heat transfer) across the exterior envelope due to improved blower effectiveness, and lower temperature settings utilized because the house was more comfortable. The impact of furnace or boiler replacement on changes in interior temperature distributions is both complex and installation-dependent, and has not been addressed in the current study.

6.3.4 Other Changes to the Heating System

The effect of the imposition of variations in the set-up and operation of the new furnaces is illustrated in Figure 6.8. Some homes, for example, had fresh air intakes installed at the same time, connecting the return air ducting system to the outdoors. Usually this was done to mitigate an expected reduction in natural air change and an accompanying increase in interior humidity levels. For high-efficiency furnaces, such homes tended to be toward the high end of the distribution of percentage savings, but the results are still widely scattered.

The placement of air conditioner coils in the supply air stream where they were absent with the old furnace, as compared to those either continuing with or continuing without central air conditioners, is shown in Figure 6.8 to have had insignificant impact on heating energy savings.

The reported installation of an electronic air cleaner or an obvious step increase in electricity consumption, both of which may be associated with the continuous operation of the furnace blower, resulted in natural gas savings which tended to be nearer the higher end of the range. As is evident in Figure 6.8, however, they were still spread out over most of the full range. This effect may at least partially result from the fact that the additional electrical energy supplied to a house to run the blower all the time also will provide an amount of by-product heating energy. In such a case, the demand for heat from the furnace is correspondingly reduced, and the apparent savings are greater.

Magnitudes of the obvious increases in electricity consumption covered a wide range, due possibly to varied amounts of time spent with the blower continuously operating, different fan speeds, etc. The largest values were in excess of 2000 kWh over the heating season which, if completely recovered as heating energy within the house, would displace about 200 to 240 m^3 of natural gas consumption, depending on the type of furnace. The relationship between electricity usage rates and natural gas usage rates in the sample houses was not pursued further during the present study.

6.3.5 New Furnace or Boiler Model

The representation of manufacturers within the various furnace and boiler categories in the final sample of 144 analyzed cases has been indicated in Section 5.2. For each of the models represented in a category, percentage savings results were found to be spread out over the full ranges shown in Table 6.1 and Figures 6.1 and 6.2. Although there are differences in process technology from one manufacturer's product to another's product which lead to slightly different energy conversion efficiencies, it is concluded from the distributions of study results that an extremely high or low fuel savings outcome determined for any one of these houses is unrelated to the brand of furnace or boiler installed.

6.3.6 Other Factors

Variables represented pictorially in Figures 6.4 through 6.8 show, at best, only weak influence on the ranges of fuel savings achieved in the project houses. Adjusted temperature settings and choice of manufacturer are also insignificant factors. Additional influences which were thought to be minor, and which were not taken into account in the identification and analysis of sample houses, include: the cleaning of ducts, the nature of modifications to ductwork other than bonnet refitting, balancing of the heat distribution network, and the skill and experience of the installer.

When acting in combination, all the above variables may be expected to contribute to differences in fuel savings from one case of a furnace or boiler replacement to another. The mutual independence of most of these factors suggests it is unlikely that particular combinations of these factors would account for the ranges of savings achieved with this sample of houses.

In comparison, it is useful to consider the following:

(a) Without taking into account other variables, a simple improvement in seasonal efficiency from a range of 55 to 70 percent to a mid-efficiency value of 80 percent results in a space-heating energy savings range of 12.5 to 31.3 %. The approximate 90 percent band of heating fuel savings determined above from the observations of project houses with mid-efficiency furnaces was 6 to 30 %.

(b) In going to a high-efficiency seasonal value reaching 95 percent from a prior 55 to 70 percent, the savings range on heating alone is 26.3 to 42.1 %. The approximate 90 percent band of heating fuel savings determined in this study was 23 to 45 % for the group of high-efficiency furnaces.

The operating performance of each replaced furnace or boiler thus could account for the extreme range of energy savings encountered. It is unknown, however, whether 55 and 70 percent are closely representative of the extremes of performance of existing gas space heating systems in Manitoba. The shape of the distribution of operating performance is also unknown. The old furnaces and boilers for the sample houses had been removed in 1985 and 1986 and were not examined in the study.

In addition to the above uncertainty about the performance of the old units, there may be some degradation of the energy-saving benefit normally provided with higher-efficiency replacements if another naturally aspirated gas appliance continues to be vented to the outdoors via the chimney. Most of the sample houses had naturally aspirated gas water heating systems and retained them when the new furnaces and boilers were installed. The effect of this on gas savings was not investigated during the study, but may be important.

When a new higher-efficiency unit replaces the conventional gas heating plant, off-cycle losses of heated air via the exhaust vent of the space heating appliance have been significantly reduced or eliminated. However, a new regime of flows is established through the remaining draft hoods or diverters. The change in total flow rates will be affected by the relative sizes of the removed and the remaining exhaust pathways to the stack, and on the change in position of the neutral pressure plane. If total flows of interior air through the non-space-heating gas appliances increase, then overall fuel savings will be adversely affected.

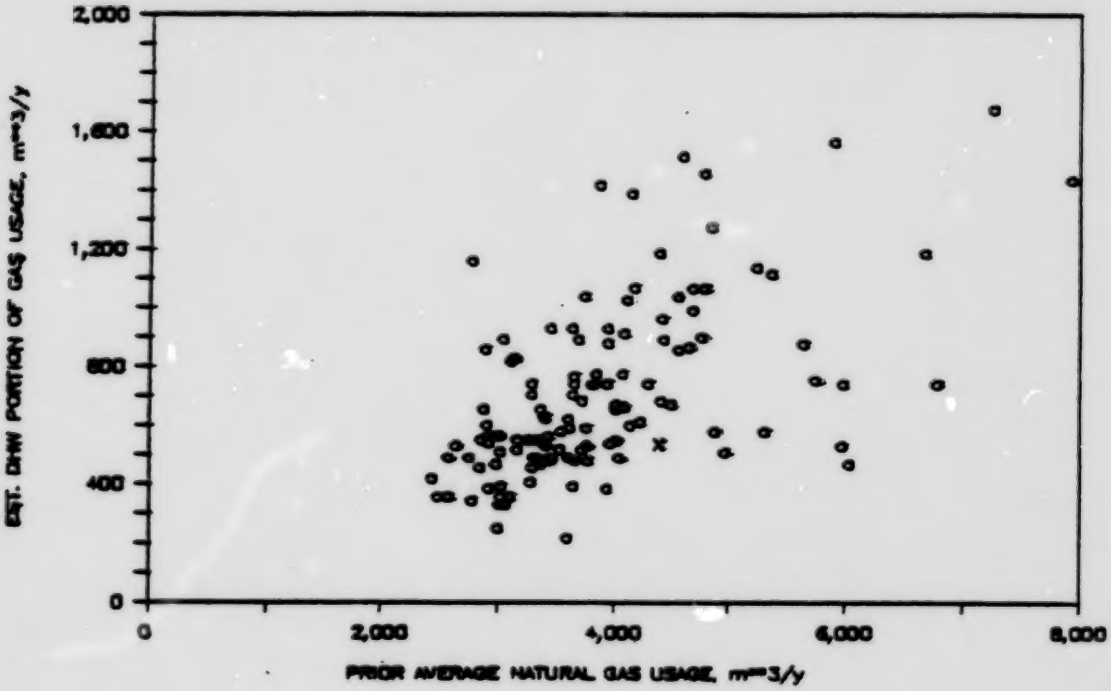
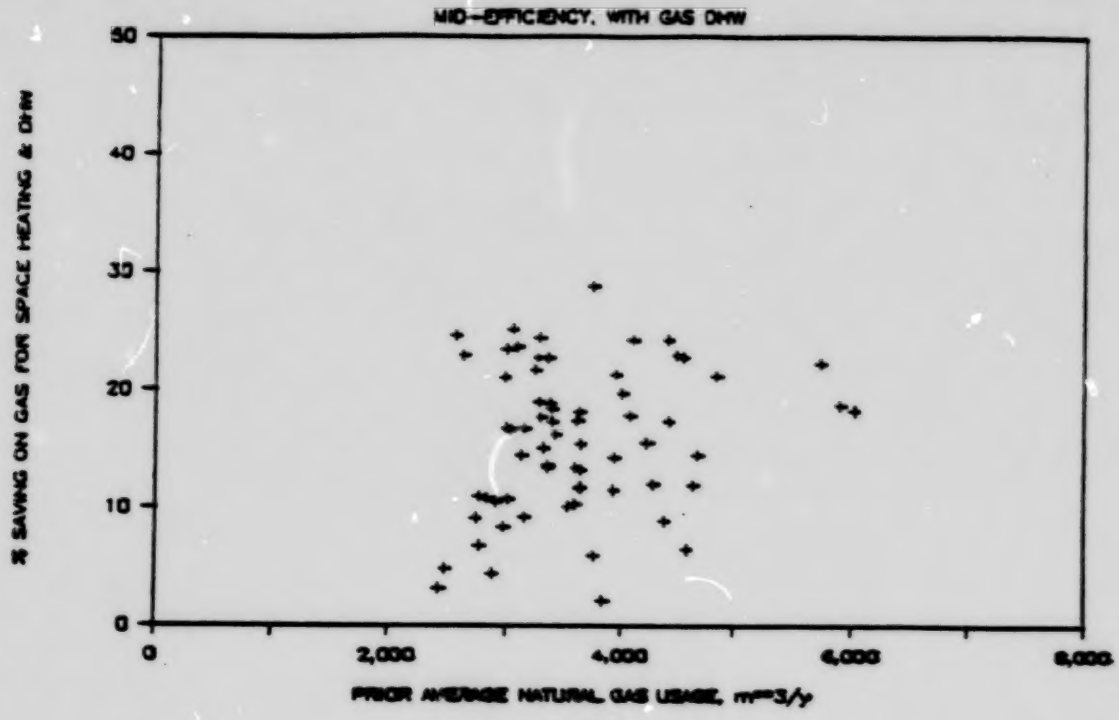


Figure 6.1 Estimated Annual Natural Gas Consumption by Domestic Water Heaters in 127 Study Homes (Example House A = "X")

TABLE 6.1 FUEL SAVINGS SUMMARY - HIGHER-EFFICIENCY SPACE HEATING EQUIPMENT

	Heating System	DHW Type	No. of Houses	Basis of Fuel Savings Calculation	Percentage Reduction in Normalized Annual Gas Consumption lowest	group average	highest
FURNACES	Mid-efficiency	gas	66	space heating + DHW	2.1	15.8	28.8
				estimated space heating only	2.7	19.2	33.6
		elec	11	space heating only	11.1	20.5	34.2
	High-efficiency	gas	49	space heating + DHW	16.9	27.5	37.2
				estimated space heating only	19.3	34.0	48.8
		elec	5	space heating only	26.7	31.5	36.3
	Upgraded Conventional	gas	6	space heating + DHW	1.0	6.9	10.5
				estimated space heating only	1.1	8.5	12.5
BOILERS	Upgraded Conventional	gas	3	space heating + DHW	1.8	10.5	17.3
				estimated space heating only	2.3	12.9	21.4
	High-efficiency	gas	3	estimated space heating + DHW	7.2	15.2	20.0
				estimated space heating only	8.2	18.1	25.8
		elec	1	space heating only	-	13.1	-



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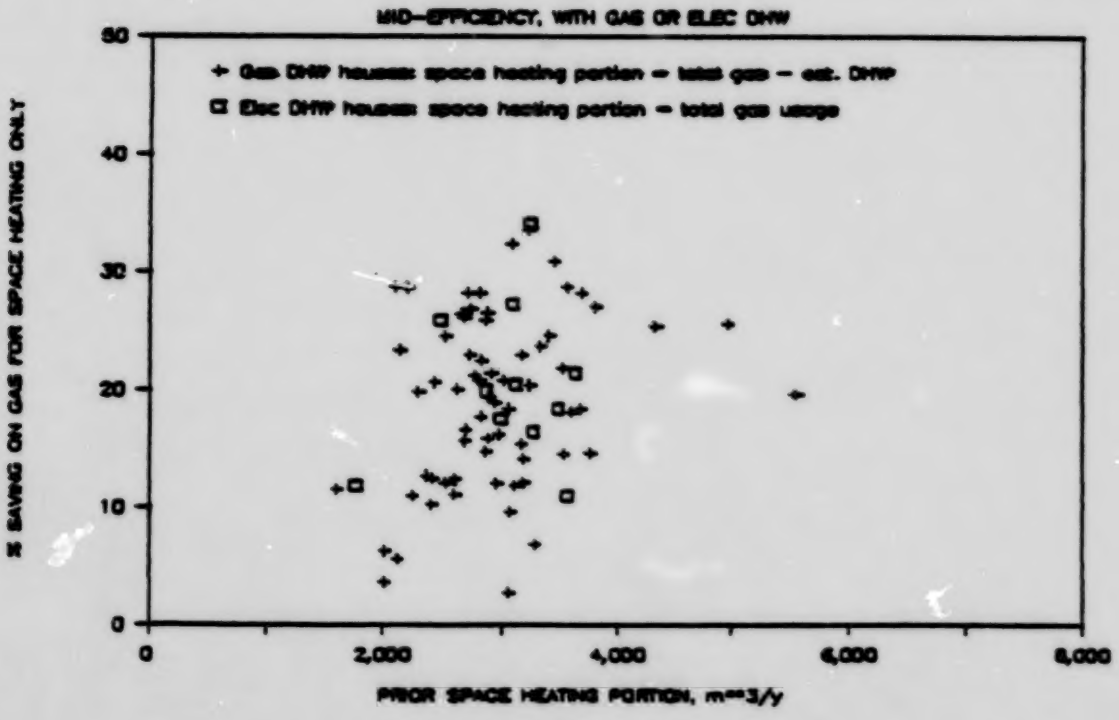
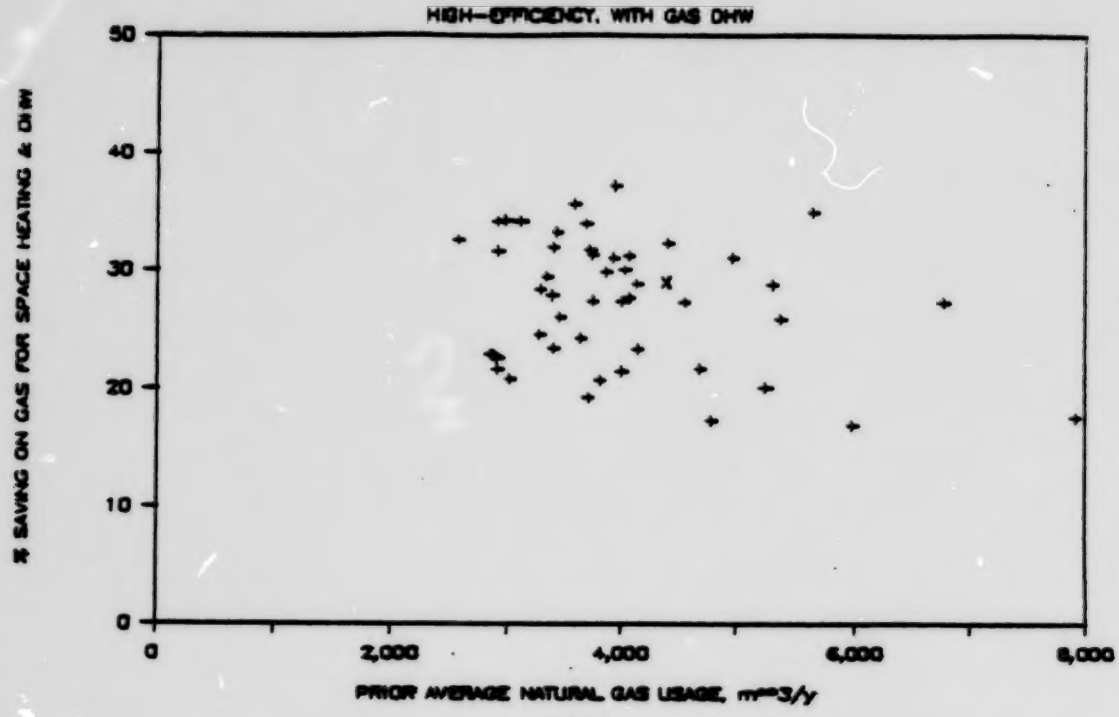


(b)

Figure 6.2 Effect of Mid-Efficiency Furnaces on Annual Natural Gas Usage: (a) Gas for Space Heating and DHW. (b) Space Heating Gas Only.



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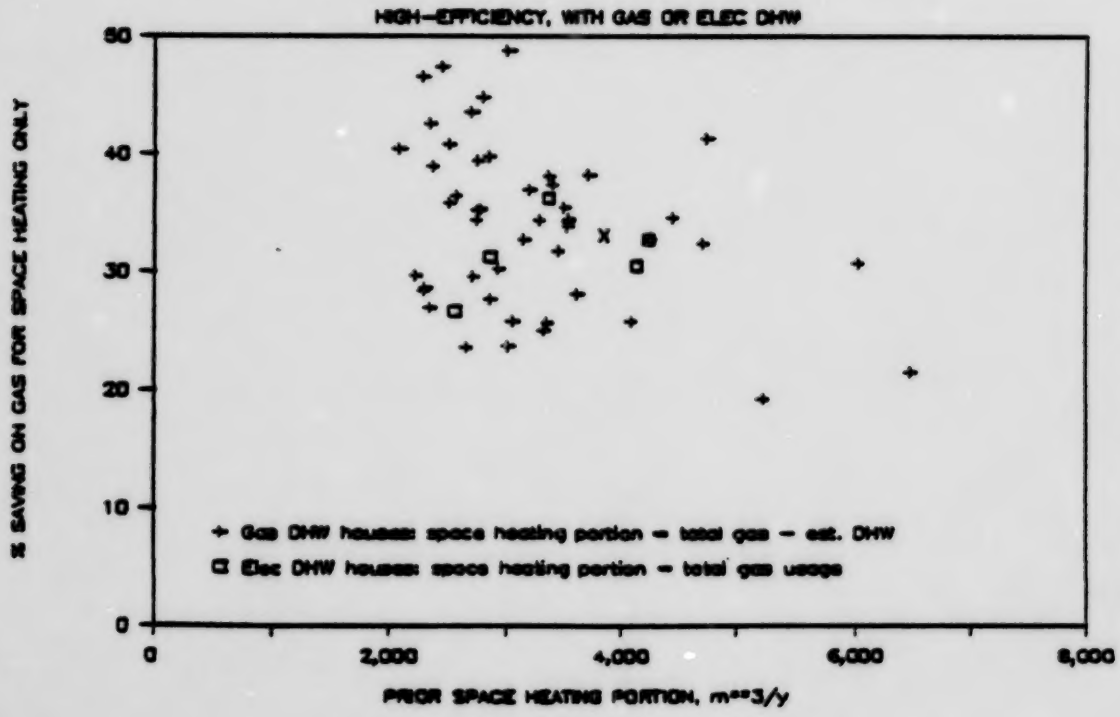
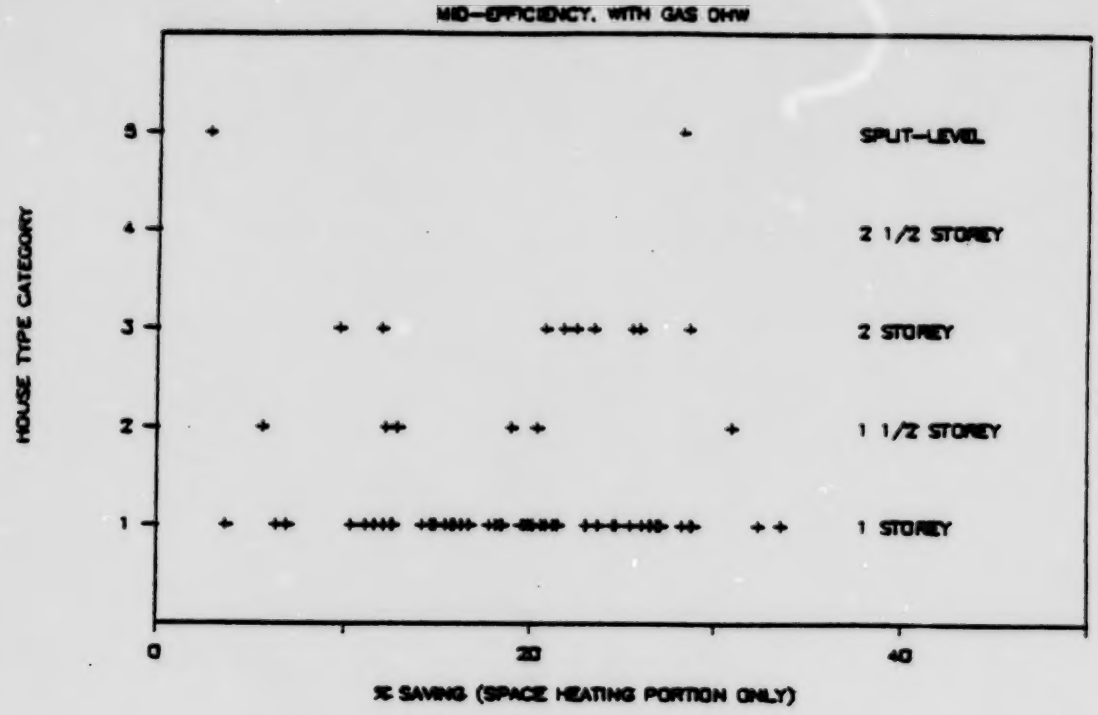


(b)

Figure 6.3 Effect of High-Efficiency Furnaces on Annual Natural Gas Usage: (a) Gas for Space Heating and DHW, (b) Space Heating Gas Only. (Example House A = "X").



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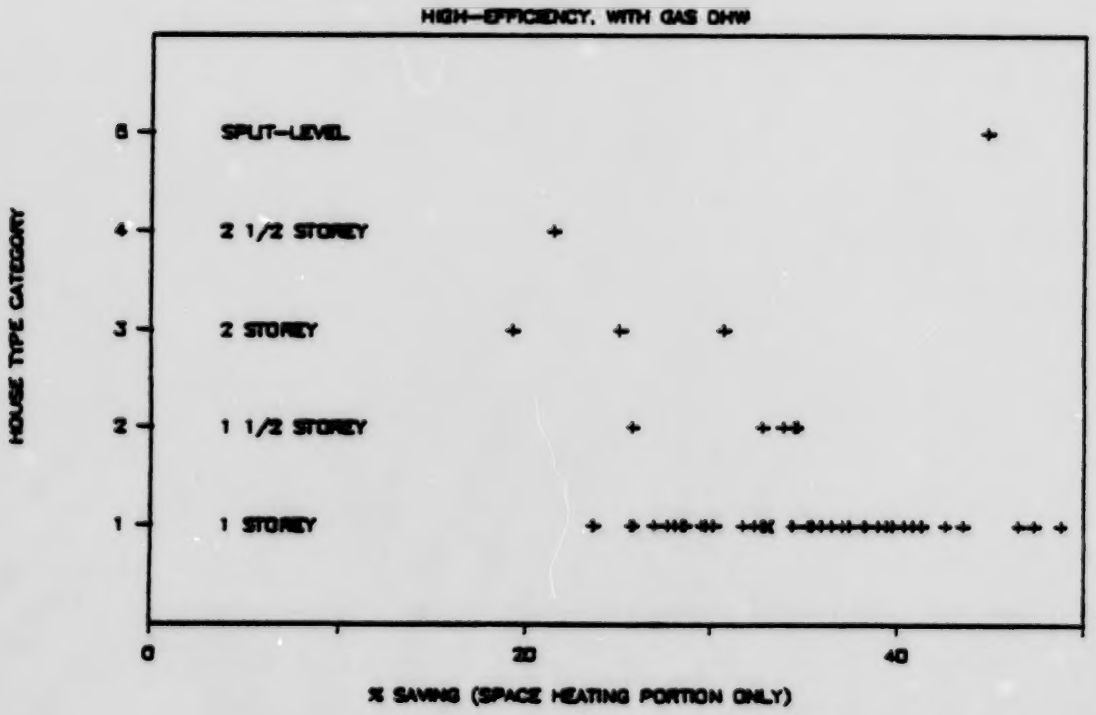
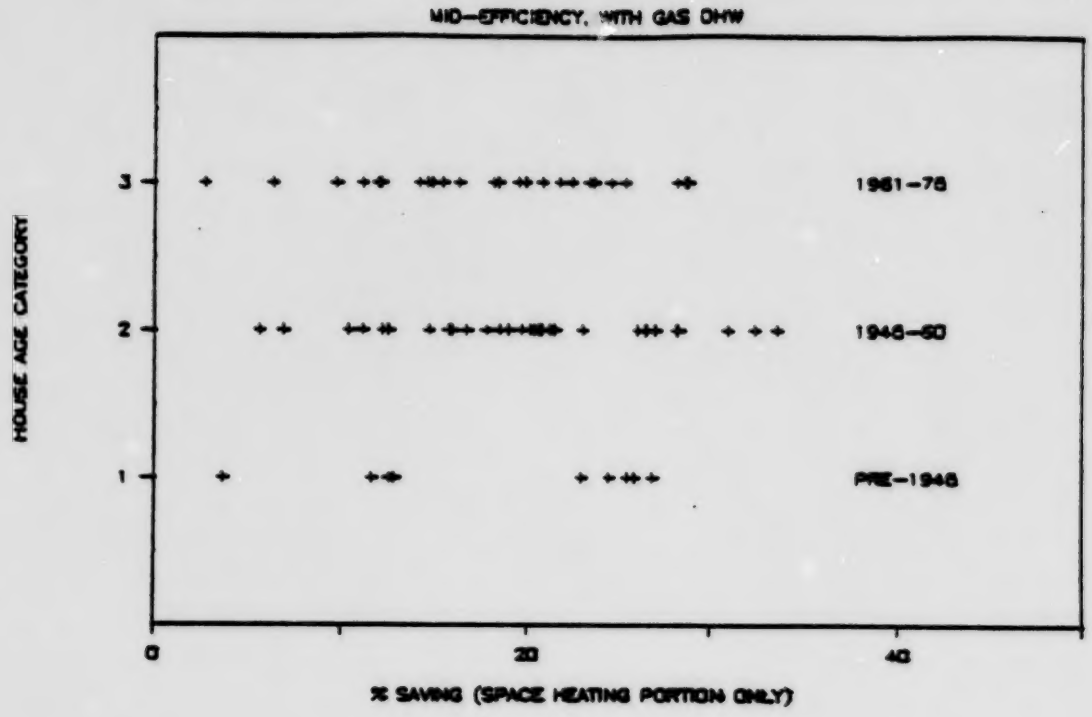


(b)

Figure 6.4 Effect of House Type on Fuel Savings with Mid- and High-Efficiency Furnaces (Example House A = "X").



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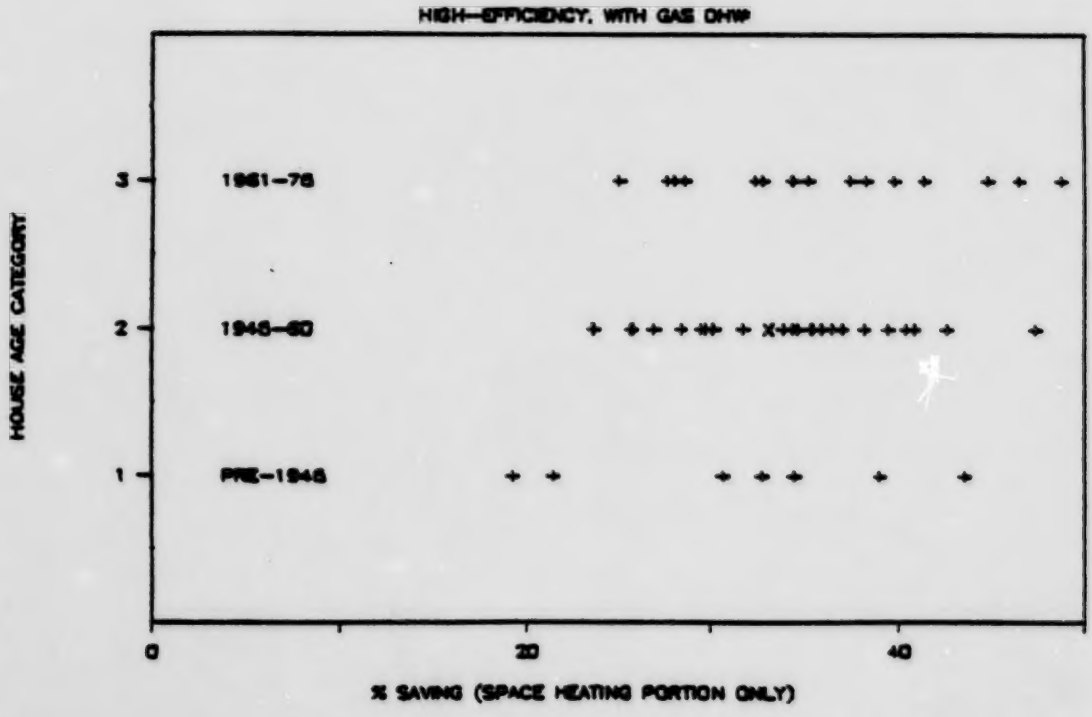
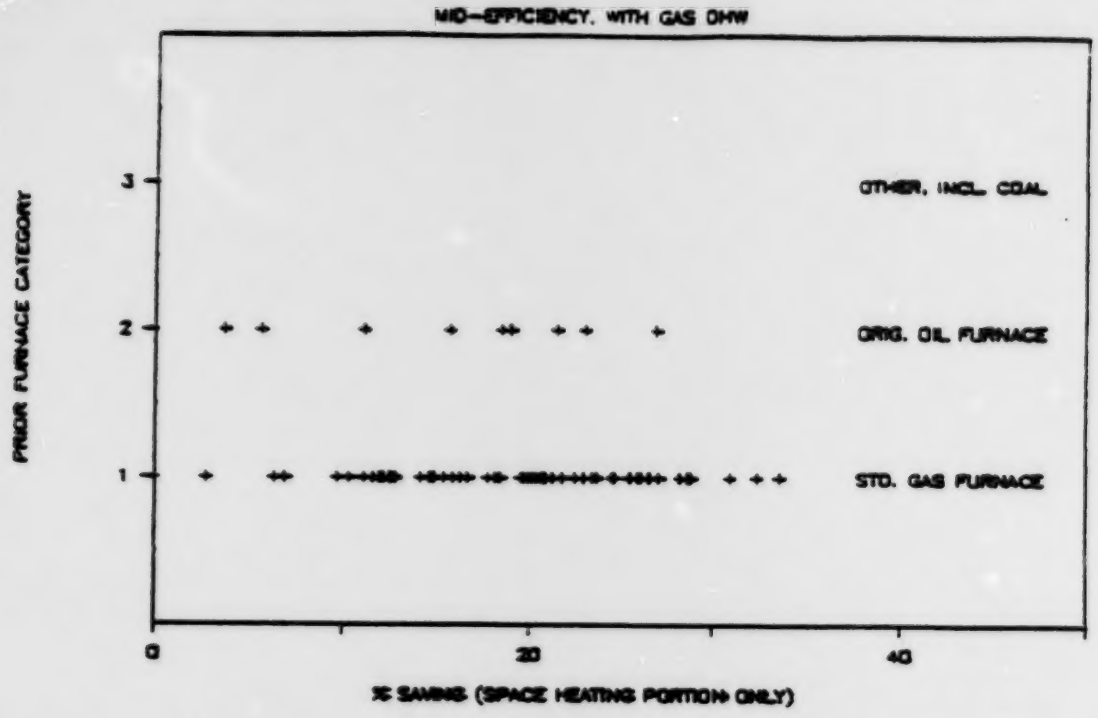


(b)

Figure 6.5 Effect of House Age on Fuel Savings with Mid- and High-Efficiency Furnaces (Example House A = "X").



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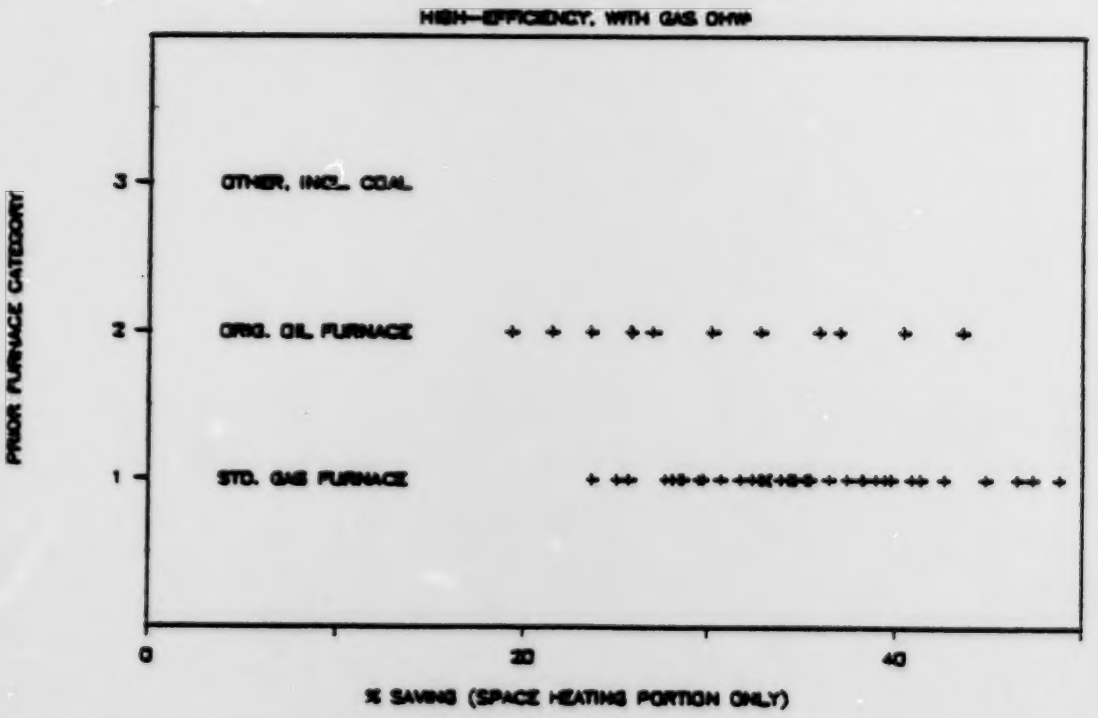
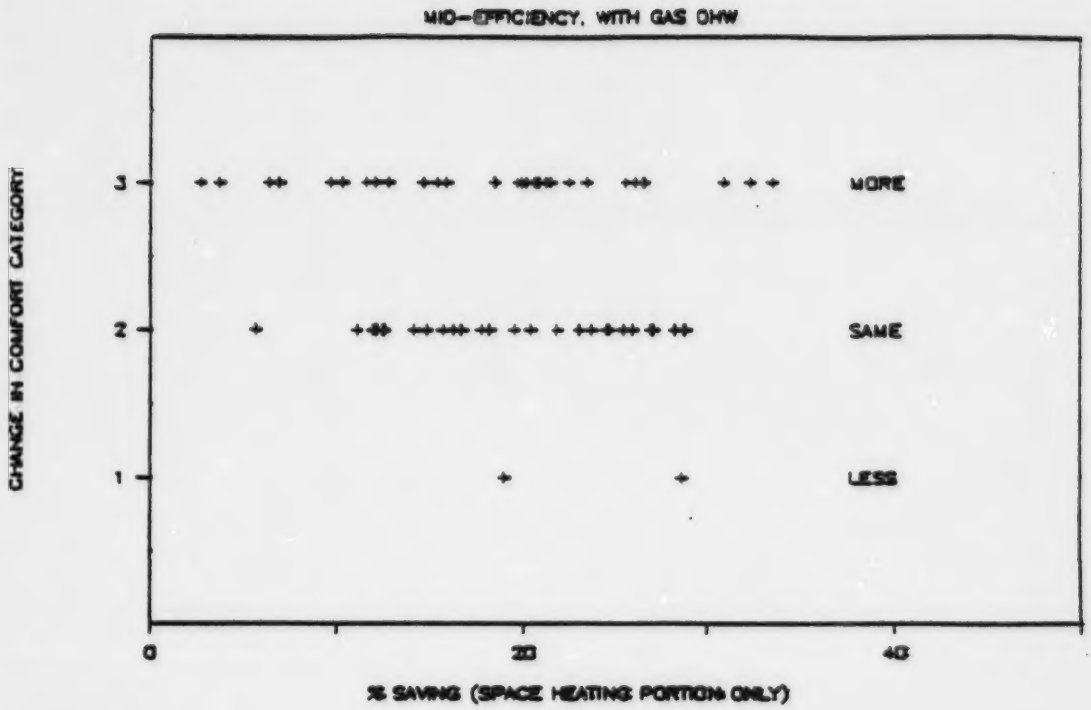


(b)

Figure 6.6 Effect of Existing Furnace Type on Fuel Savings with Mid- and High-Efficiency Furnaces (Example House A = "X").



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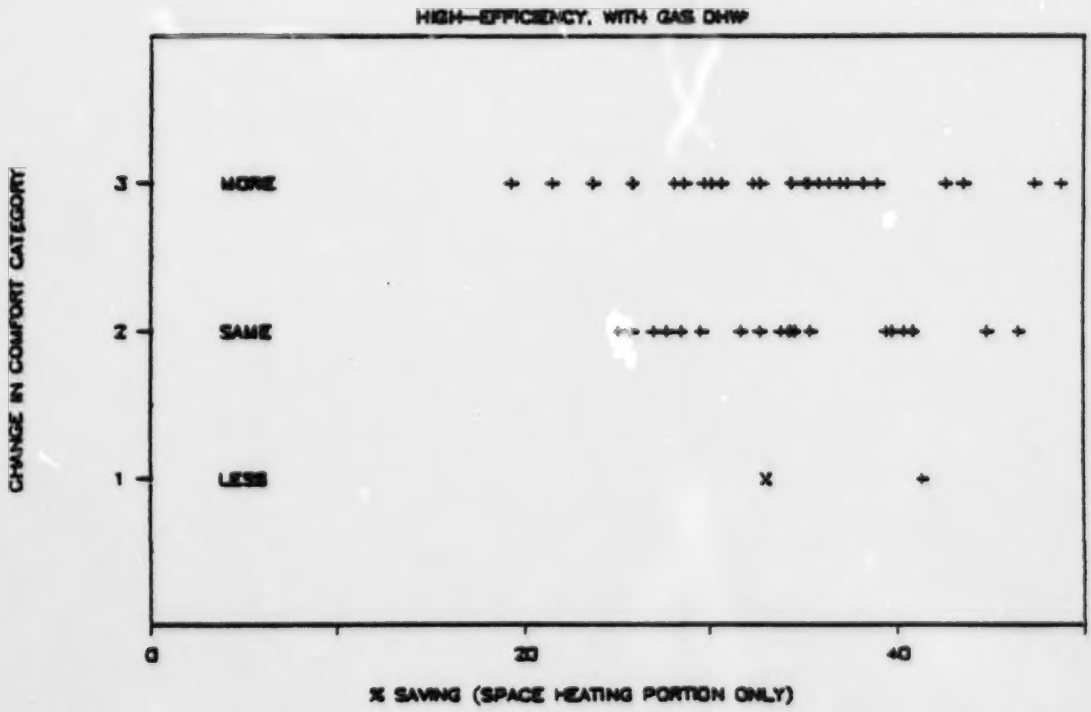
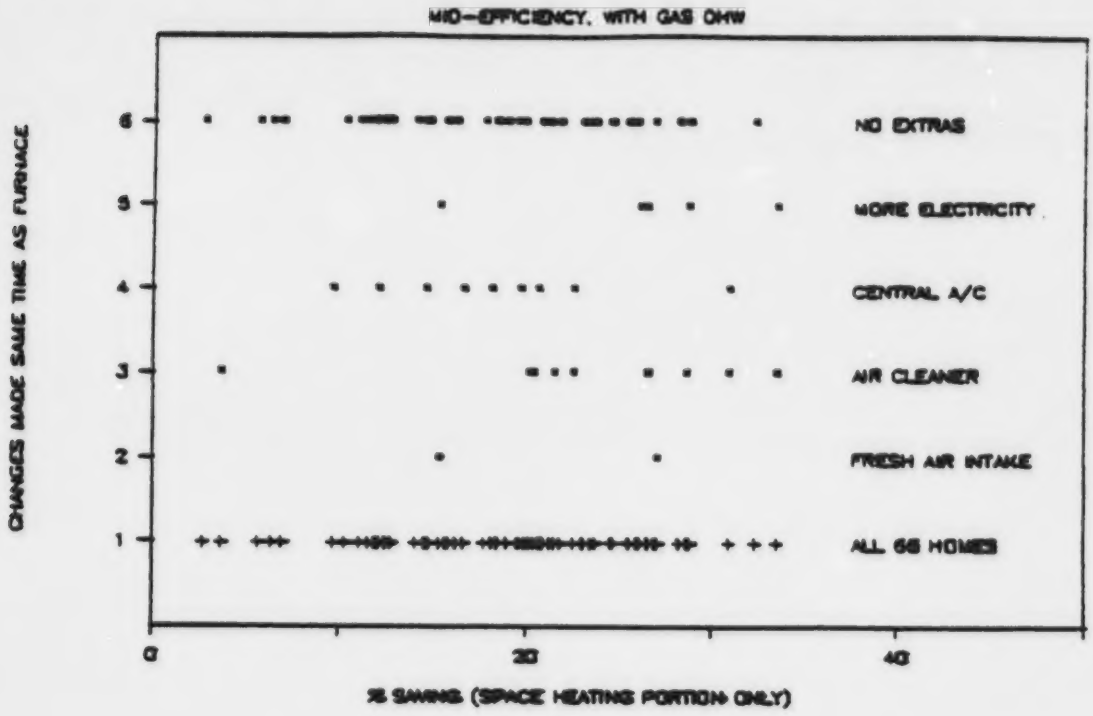
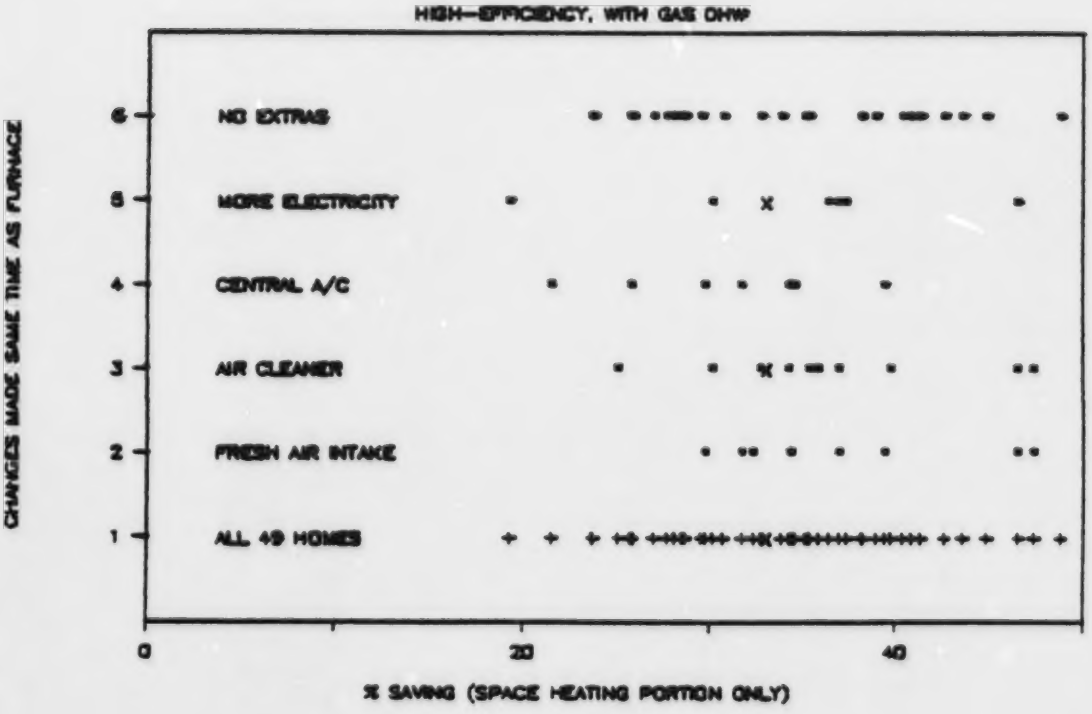


(b)

Figure 6.7 Effect of Comfort Change on Fuel Savings with Mid- and High-Efficiency Furnaces (Example House A = "X").



(a)



(b)

Figure 6.8 Effect of Other Changes on Fuel Savings with Mid- and High-Efficiency Furnaces (Example House A = "X").

Section 7

HOMEOWNER EXPERIENCES

7.1 REASONS FOR REPLACEMENT

Figure 7.1 is a comparison of the reasons cited for replacing the existing furnace or boiler. Just under 40 % of the responding homeowners replaced their furnaces because the old unit failed (39 % for furnaces, 33 % for the small sample of boilers). In most cases the old heat exchanger had cracked or corroded. Of the others, many respondents indicated that they had taken pre-emptive action, feeling that the old unit was too old or unlikely to last much longer without trouble. Breakdown or perceived risk of breakdown was thus the main motivation for replacement in two-thirds of the sample homes (66 % for furnaces, 44 % for the boilers).

The desire for lower heating bills or greater comfort was cited as the main reason for installing the new heating plant in 14 and 4 % of the homes with furnaces, respectively. For the few boiler cases represented in the sample, the cost of heating was the most common single reason for replacement stated by respondents to the questionnaire (44 %).

The age and type distribution of the replaced furnaces and boilers is shown in Figure 7.2. Nearly three-quarters of the total number of replaced units in the sample were standard gas furnaces and boilers. About 45 % of these were replaced due to failure of the old unit. Other reasons for replacement were significantly more important than failure when the unit was an old oil or solid fuel unit that had earlier been converted to run on natural gas. The bulk of the replaced units were between 20 and 30 years old. Of those less than 20 years old, failure was cited as the reason in just over half the cases.

7.2 SELECTION CRITERIA

When the old system failed, there was a tendency to do less shopping for a replacement, but urgency does not seem to have been a dominant factor. Figure 7.3 shows this in terms of the number of quotations obtained prior to installation. Many of the failed units were replaced in the spring or fall after inspection revealed heat exchanger failure. Those investing in high-efficiency furnaces were more likely to decide on the basis of one quotation than were those purchasing a less expensive mid-efficiency unit, and this difference was greater if the old furnace had failed. The single quotation category includes a few respondents who acted without seeking an estimate.

Choice of make and model was strongly influenced by heating contractors' recommendations, as shown in Figure 7.4, and reliance upon the heating contractor was greater when the old furnace or boiler had failed. For mid-efficiency furnaces this increased reliance displaced the importance of the manufacturer's reputation and price. For the high-efficiency furnaces, most of the shift in emphasis when the old unit failed was away from the manufacturer's reputation and advertisements and toward the recommendations of heating contractors and friends, neighbours, or relatives. Price was less important to purchasers of high-efficiency furnaces than to those who acquired mid-efficiency units.

7.3 SERVICE AND REPAIRS

From the time of installation (between September 1985 and August 1986) to the end of 1987, 110 of the 326, or about one-third, of the higher-efficiency furnaces and boilers in the sample required the attention of the heating contractor or service person, slightly higher for mid-efficiency furnaces and all boilers, and slightly lower for high-efficiency furnaces. The distribution of service visits is shown in Figure 7.5. Normal visits for checking, cleaning, and adjusting are not included in the totals shown in the figure.

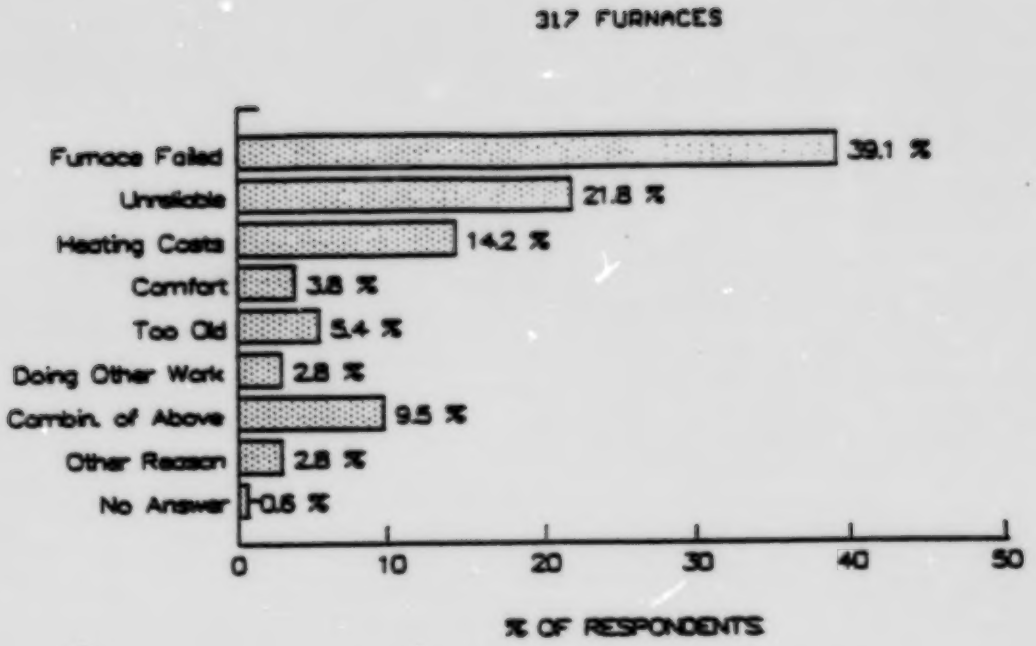
Most of the site visits were prompted by shutdowns of the furnace or boiler triggered by improperly functioning sensors or switches, situations which were typically corrected through adjustment or replacement. Homeowners who reported service visits were asked about the types of problems they had experienced, and their answers are shown in Figure 7.7. Interior noise related to fans and ignition sequencing was a concern to 38 % of them, slightly more for mid-efficiency units, and slightly less for high-efficiency units.

A greater proportion with high-efficiency furnaces than with mid-efficiency furnaces reported interior and/or exterior moisture problems. On the interior, for example, elevation of humidity to an undesirable level was cited in 24 % of the high-efficiency cases where a service visit was made for any reason. The comparable interior figure for mid-efficiency furnaces and incidence of a service visit was 9 %. Exterior moisture problems usually amounted to a buildup of ice in the vicinity of the exterior wall terminal of the flue for high-efficiency furnaces and boilers.

Condensation within the chimney or flue was a greater problem with mid-efficiency units, being reported in 12 % of the mid-efficiency cases where a service visit was made for any reason. Of the 180 mid-efficiency furnace responses, 8 % reported that the chimney had been relined when the new furnace was installed. It was not ascertained whether the new liners were downsized to suit the new furnaces. For the other 92 % of the mid-efficiency furnace installations, the existing chimney was unaltered, and the new furnace was common-vented with the naturally aspirated domestic water heater, if present. An attempt to reduce flue condensation by surrounding the existing chimney liner with zonolite was tried in one or two cases. In a few other cases, the flue was later downsized/relined.

Corrosion was almost absent as a reported problem. It is noted, however, that the equipment represented in the study sample had only been in operation for 1 1/2 to 2 1/2 years at the time the homeowners were polled, and that incidence of corrosion may not be readily apparent or be easily identified by the layman.

Most of the site visits were made at no cost to the homeowners. For those 18 respondents who actually incurred an expense, the nature of the problems they reported and the amounts spent are outlined in Figure 7.8.



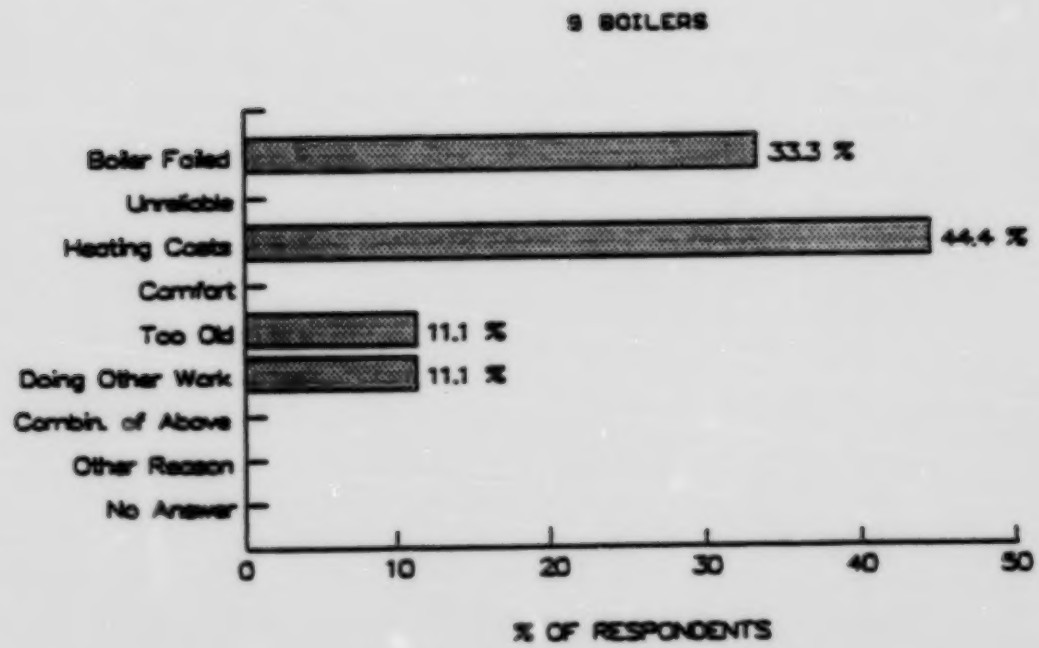


Figure 7.1 Reasons for Furnace or Boiler Replacement

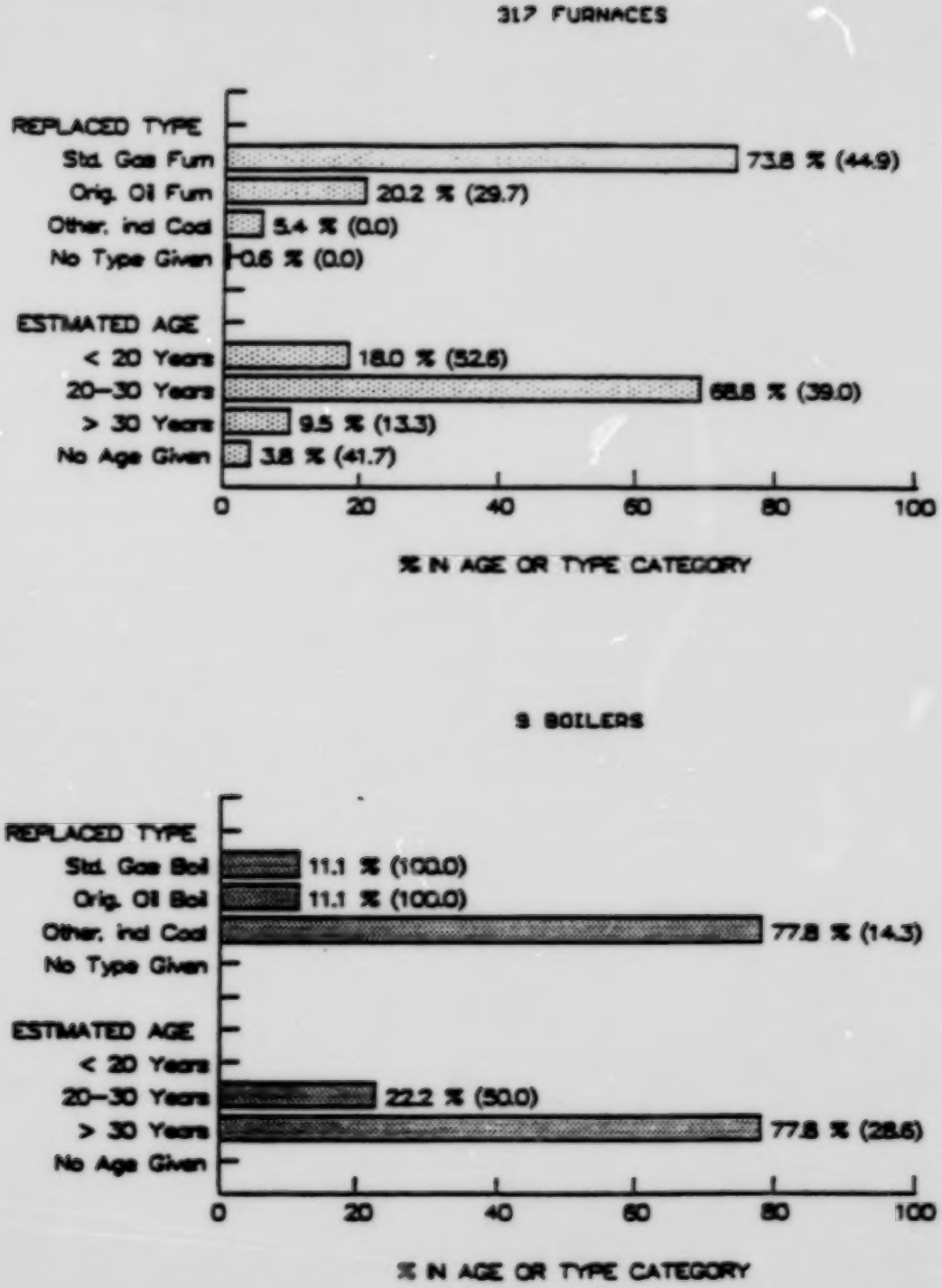


Figure 7.2 Types and Ages of Replaced Heating Plants (number in parentheses is the percentage of furnaces or boilers in the type or age category which were replaced due to failure).

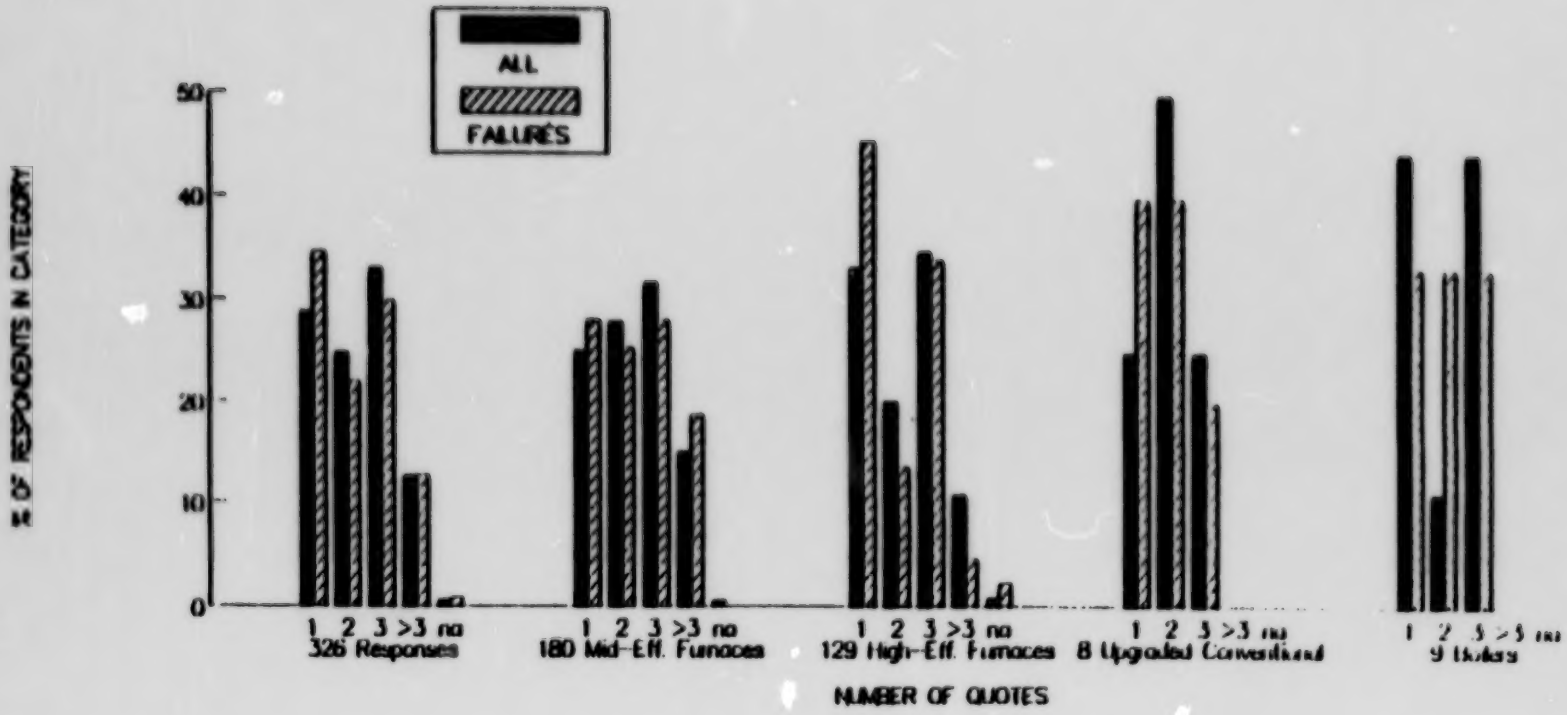


Figure 7.3 Number of Quotations Obtained Prior to Selection of New Furnace or Boiler

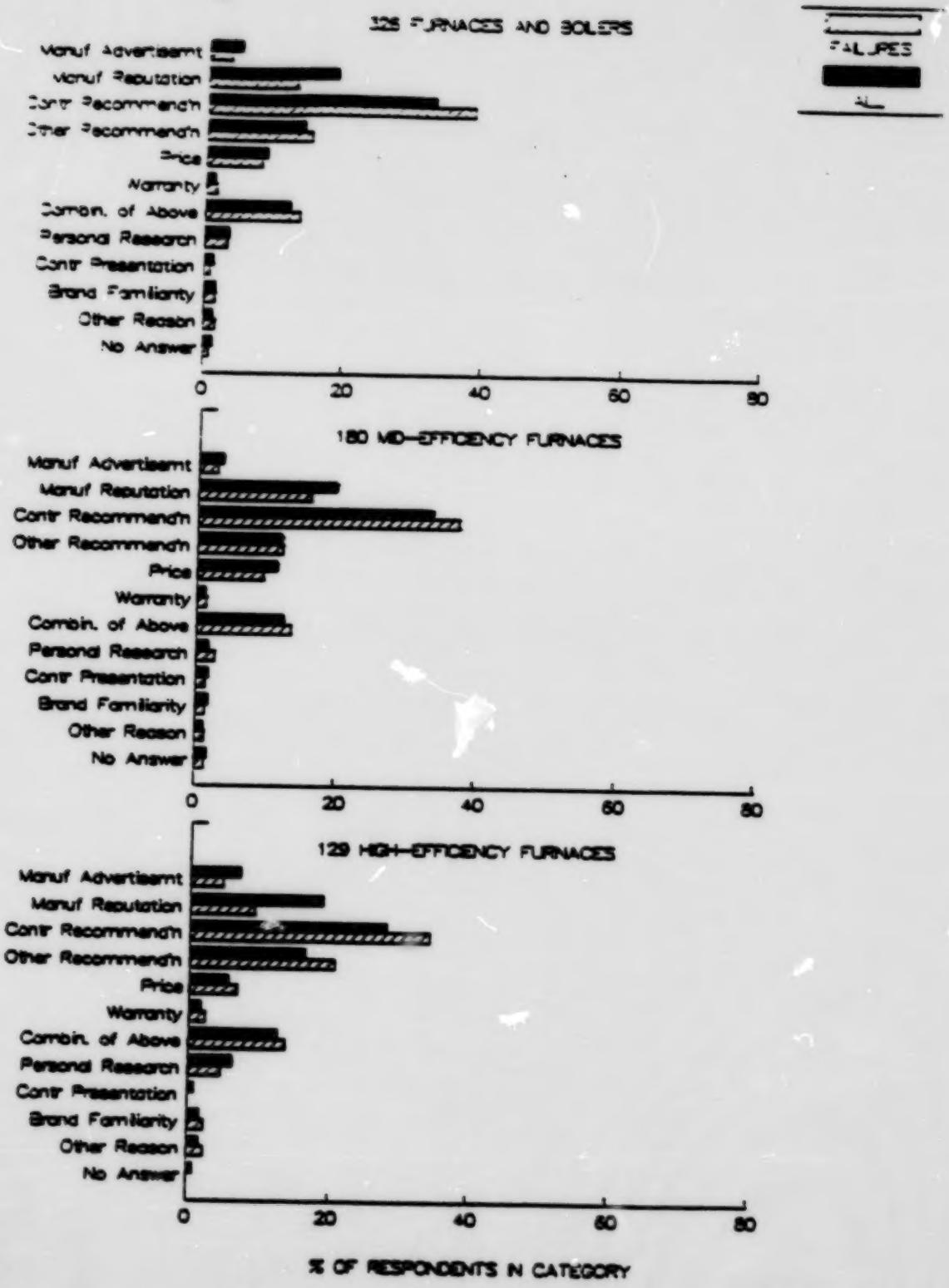


Figure 7.4 Reasons for Choice of Make and Model

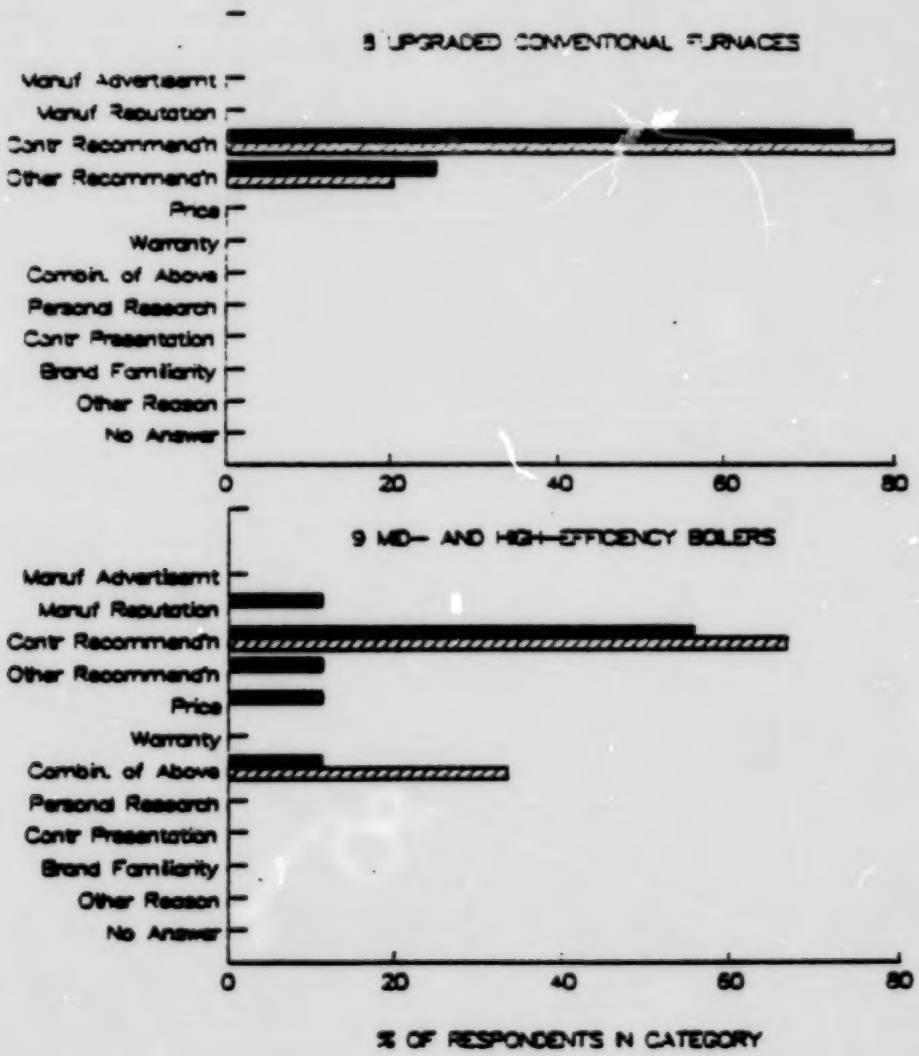


Figure 7.4 (continued)

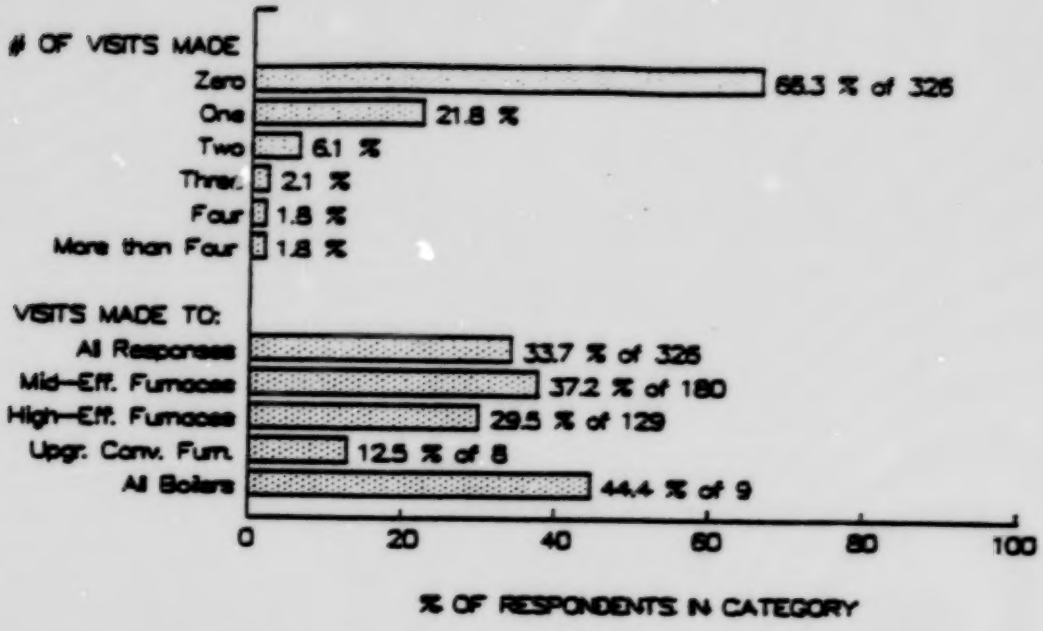


Figure 7.5 Distribution of Non-Routine Service Visits

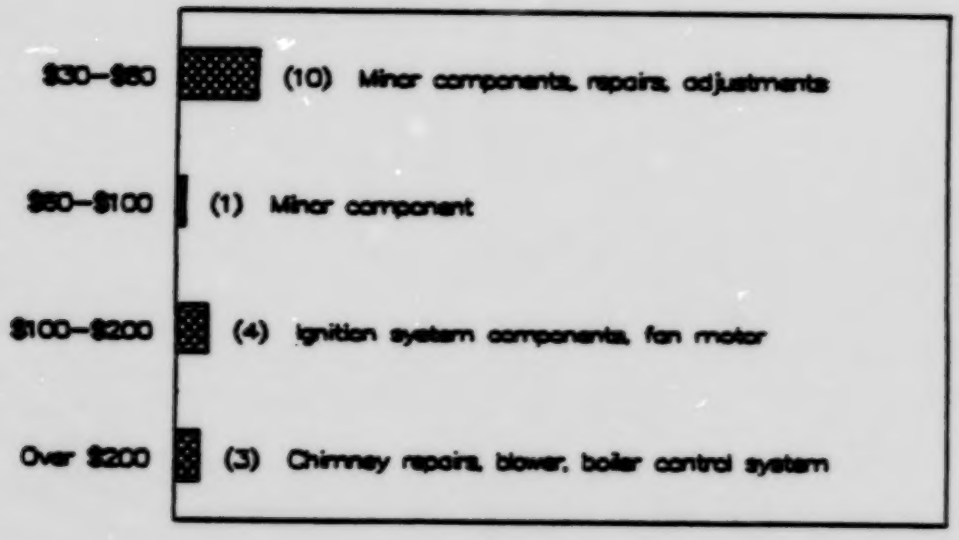


Figure 7.6 Reported Problems Involving Expense (number in parentheses is the number of occurrences in the expense category: sample size = 326).

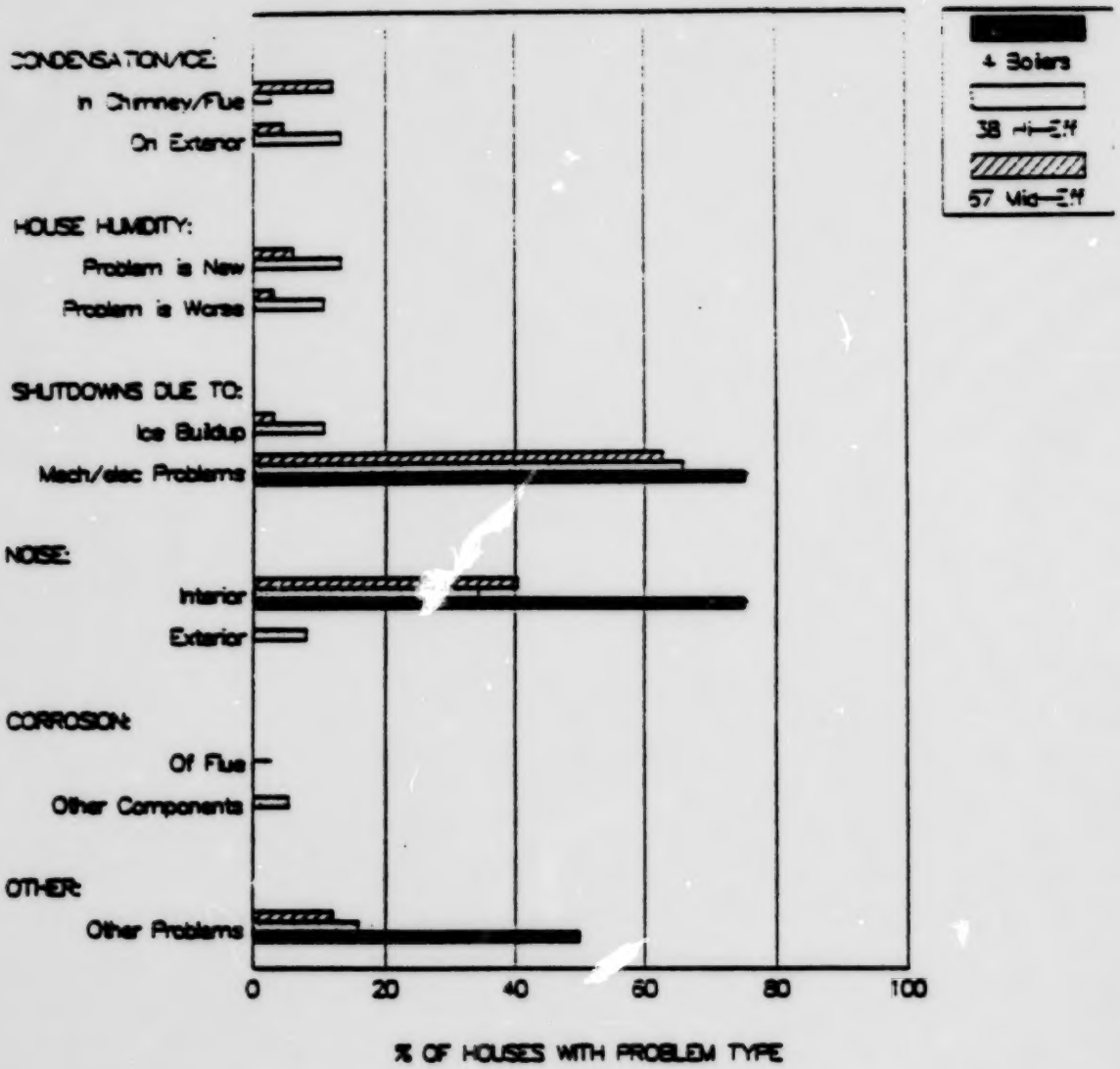


Figure 7.7 Types of Problems Noted by Homeowners Who Received Non-Routine Service Visits

Section 8

CONCLUSIONS

Owners of 983 homes which had been retrofitted with nigher-efficiency gas furnaces or boilers were requested to complete a questionnaire on the subject of their new heating systems and to grant project personnel access to the utilities' records of their energy consumption. Analysis of weather-normalized energy savings was eventually completed on a final high-quality sample of 144 houses chosen from 326 valid candidates. Within the sample were represented a variety of house styles, sizes, ages and occupancies, and a market-wide selection of higher-efficiency forced air furnaces and hot water boilers. About 97 % of the houses in the surveyed sample had forced air heating systems, and about 3 % had hot water systems.

The range of natural gas savings achieved in the final sample of project houses was found to be quite broad for each furnace and boiler type, and individual results were well distributed within the ranges:

(a) Sample homes with gas domestic water heaters and replacement mid-efficiency (induced draft) furnaces saved an average of 15.8 % on the total annual gas consumption. The corresponding result for the estimated space heating portion of the total gas consumption was an average saving of 19.2 %. For a small subsample of houses with electric domestic water heaters and mid-efficiency furnaces, the average gas usage reduction was 20.5 %.

(b) For high-efficiency (condensing) furnaces in houses with gas domestic water heaters, the average reduction was 27.5 % on total gas consumption. The average saving on the estimated space heating portion was 34.0 %. In a small subsample of homes with electric domestic water heaters and high-efficiency furnaces an average reduction in gas consumption of 31.5 % was achieved.

(c) The savings in a group of gas-DHW houses whose replacement furnaces were upgraded conventional models (naturally aspirated furnaces fitted with automatic flue dampers and intermittent pilots) averaged 6.9 % on total gas consumption, and 8.5 % on the estimated space heating portion.

(d) In two small subgroups of houses with hot water heating systems, the average gas savings on total consumption were 10.5 % and 15.2 % for upgraded conventional and high-efficiency replacement boilers, respectively. On the estimated space heating portion only, the corresponding average savings were 12.9 and 18.1 %.

(e) In mid- and high-efficiency furnace subsamples with enough houses to observe trends, the bands of gas savings were on the order of 20 % wide and were well distributed about the average values noted above. Such factors as house style, age, size, occupancy, and furnace or boiler manufacturer, which could enhance or reduce the benefit of a heating system improvement, appeared to have effects which were an order of magnitude smaller than the observed ranges of savings. However, although determination of actual values was beyond the scope of the current study, it was noted that a conceivable range of operating

efficiencies for the old heating systems would have been sufficient to produce the high and low values for savings that actually occurred. Retention of an open chimney for other gas-burning appliances may also have an effect on the overall fuel savings which result from installation of a higher-efficiency furnace or boiler.

On homeowner experiences with the selection, installation, and operation of the new higher-efficiency furnaces and boilers, it was found that:

(a) Actual failure or perceived risk of failure of the existing heating system was the prime reason for replacement cited by about two-thirds of survey respondents. Desire for greater comfort or lower heating bills was only a minor consideration for the study group.

(b) Almost 70 % of the replaced heating plants were between 20 and 30 years old, and more than 70 % were standard gas furnaces.

(c) Three was the most common number of quotations obtained by homeowners prior to selection of the new furnace or boiler, but almost as many instances of only one or two quotations being obtained were reported. Whether or not the old unit had failed made only a slight difference to the number of cost estimates sought.

(d) The heating contractor's recommendation was the most important cited reason for deciding upon the make and model of higher-efficiency furnace or boiler which was eventually installed. Reliance upon the heating contractor was slightly greater in the case of the old unit having failed.

(e) One-third of the survey respondents reported that non-routine service visits to address problems related to the new heating system had occurred during the 1 1/2 to 2 1/2 year period between the date of installation and the time of the survey. Most of the visits were prompted by system shutdowns. Very few involved an expense by the homeowner.

Section 9

RECOMMENDATIONS

In light of the wide ranges of percentage savings which occurred in groups of actual Manitoba installations of higher-efficiency furnaces and boilers, and the lack of a complete understanding of the reasons for the ranges, the following are recommended:

(a) Groups with interest in the replacement market for gas space heating systems should be made aware of the ranges of savings which occur when higher-efficiency units are installed. The interest groups may include:

(i) the consumer, who, when formulating a decision to purchase a new gas heating system, may benefit from the possession of a realistic expectation of product performance,

(ii) government and building officials, who may find the information useful in planning for development, energy supply management, etc., and

(iii) the heating industry, which may wish to make use of the information in marketing its products and services and in customer relations.

(b) Consistent means of reporting performance characteristics of heating equipment, in a format meaningful to the consumer, should be devised and adhered to by the heating industry, governments, and other officials.

(c) A greater ability to determine and predict heating system performance in the field should be acquired. This may include better understanding of the causes of variability in performance, and how to limit the variability through improved maintenance and installation procedures. Advances in this area will help the three groups above to a more complete perspective of the benefits of standard- and higher-efficiency equipment. In particular, investigation into the following areas is suggested, within the Manitoba context:

(i) the distribution of in situ operating efficiencies for conventional gas furnaces more than 20 years old,

(ii) the distribution of operating efficiencies for newly installed conventional gas furnaces and higher-efficiency units,

(iii) a valid method of estimating seasonal efficiency from spot or short-term measurements in the field,

(iv) the value of delaying replacement through taking no action, applying a tune-up, or refurbishing,

(v) the effect on overall flue draft, and on fuel savings, of removing only the space heating appliance's off-cycle draft when the appliance is replaced with a higher-efficiency unit, and

(vi) the effect of higher-efficiency heating equipment on building interior temperature distributions, particularly in relation to the interior environment maintained with conventional equipment.

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APPENDIX A

QUESTIONNAIRE

The introductory letter, utility release form, and questionnaire which follow in this section were mailed to the homes with replacement higher-efficiency furnaces. A similar package was sent to higher-efficiency boiler owners. All survey questions about boilers were the same as those for furnaces, except for question 8, in which the choices "Installed Fresh-Air Intake", "Installed Humidifier", "Installed Electronic Air Cleaner", and "Installed Central Air Conditioning" were replaced by "Added Circulating Pump", Replaced Circulating Pump", and "Added or Modified Piping".

Manitoba

Energy and Mines | Energy Management | 555 — 330 Graham Avenue
Winnipeg, Manitoba, CANADA
R3C 4E3

December, 1987

Dear Homeowner:

RE: STUDY OF THE SAVINGS ACHIEVED BY HIGH-EFFICIENCY GAS FURNACES AND BOILERS

Your assistance is requested regarding a study being conducted by Manitoba Energy and Mines in cooperation with Energy, Mines and Resources Canada.

Many Manitoba homeowners contact us for advice on whether it is a worthwhile investment to replace an older, conventional gas furnace or boiler with a new, more efficient unit. This Study will enable us to better inform consumers on the benefits and drawbacks of a change in heating equipment.

The Study will involve examining the natural gas meter information for a cross-section of homes in Winnipeg where gas permit records indicate that an older, forced-air furnace or hot water boiler has been replaced with a new, more efficient unit. The analysis will be done by UNIES Ltd. (Consulting Engineers) of Winnipeg.

To help us, please fill out the attached permission form and questionnaire and return them as soon as possible in the enclosed postage-paid envelope. Your name and address will be kept strictly confidential. If you have any questions concerning the questionnaire or the project, please contact Dr. Campbell MacInnes (633-6363).

Although we are primarily interested in the changes in energy consumption, we are also interested in your experiences and general level of satisfaction with your new heating system. Responses to the questions on the next several pages will give us insight into possible common problem areas and help us to account for factors other than the new furnace or boiler which may have contributed to changes in meter readings.

At the conclusion of our Study, homeowners who have responded will be sent a copy of the results. We thank you in advance for your cooperation.

Yours truly,

K Klassen

C.D. MacInnes

KEN KLASSEN
Program Manager
Manitoba Energy and Mines
(204) 945-2792

CAMPBELL MacINNES, P.Eng.
UNIES Ltd.
(Consulting Engineers)
(204) 633-6363

KK/jw

Att'd.

STUDY OF THE SAVINGS ACHIEVED BY HIGH-EFFICIENCY GAS FURNACES AND BOILERS

PART A PERMISSION TO ANALYZE METER READINGS

Utility companies require us to obtain your permission before they will permit us to examine your meter reading records. Please complete the following to provide this authorization (electricity records will only be examined if necessary to clarify the reasons for any unusual patterns which may appear in the natural gas records):

> This authorizes Manitoba Energy and Mines or their Representatives to obtain information regarding my natural gas and electricity meter readings. This information is to be used only in conjunction with the "Study of the Savings Achieved by High-Efficiency Gas Furnaces and Boilers".

(PLEASE PRINT)

_____
(Name)

_____
(Street Address)

Winnipeg, Manitoba

_____ _____
(Postal Code) (Telephone)

_____ _____
(Signature) (Date)

Which Hydro serves your home?

○ Manitoba Hydro ○ Winnipeg Hydro

PART B QUESTIONNAIRE

Please answer as many of the following questions as you can. If you are unsure of a response or only have partial information, please fill in as much as you know and continue with the next question.

1. Which of the following best describes why you chose to replace the old furnace? (Please choose only one answer)
   - ○ Old Furnace Failed
   - ○ Old Furnace Was Not Reliable
   - ○ Wanted to Reduce Heating Bills
   - ○ Wanted to Make Home More Comfortable
   - ○ Other (Please Specify) _____

2. The old gas furnace was:
   - ○ Standard-Type with Pilot Light
   - ○ Converted from An Oil-Burning Unit
   - ○ Converted from A Coal-Burning Unit
   - ○ Other (Please Describe) _____

3. Approximately, how old was the old furnace at the time of its replacement? _____ Years

4. How many quotes did you obtain before selecting a new furnace?
   - ○ One
   - ○ Two
   - ○ Three
   - ○ More Than Three

5. When was the new furnace installed? _____
   (Please indicate month and year)

6. What is the make and model of your new furnace?
   _____

7. Which of the following best describes why you chose this particular make and model? (Please choose only one answer)

- ○ Manufacturer's Advertisement
- ○ Manufacturer's Reputation
- ○ Recommended by Heating Contractor
- ○ Recommended by Friend/Neighbour/Relative
- ○ Price
- ○ Warranty
- ○ Other (Please Specify) _____

_____

8. Did you have any of the following work done at the same time the new furnace was installed? (Please check as many as apply)

- ○ Relined Old Chimney
- ○ Replaced Thermostat with Setback-Type
- ○ Installed Fresh-Air Intake
- ○ Installed Humidifier
- ○ Installed Electronic Air Cleaner
- ○ Installed Central Air Conditioning
- ○ Added or Modified Ductwork
- ○ Other (Please Specify) _____

_____

9. What was the cost for the new furnace including installation and Provincial Sales Tax? $_____
(Please do not include cost of other work such as electronic air cleaners, etc.)

10. What is your estimate of how much your new furnace has reduced your heating costs? $_____ per year

11. What type of hot water tank does your home have?

- ○ Natural Gas
- ○ Electric

12. *How are the new furnace and hot water tank vented?*

(Please check as many as apply)

- ○ *Furnace Vented to Outdoors Via A Wall Vent*
- ○ *Furnace Vented to Outdoors Through the Roof*
- ○ *Furnace and Hot Water Tank both Vented into Old Chimney/Flue*
- ○ *Hot Water Tank Vented Alone into Old Chimney/Flue*

13. *How many times has your new furnace required repairs or adjustment?*

(Do not include regular servicing)

- ○ *Never*
- ○ *One*
- ○ *Two*
- ○ *Three*
- ○ *Four*
- ○ *More Than Four*

If answer is "Never", skip to Question 18; otherwise proceed to Question 14.

14. *Which of the following problems have you experienced with the new furnace:*

Condensation or Icing (Please check as many as apply)

- ○ *In the Chimney/Flue*
- ○ *On the Exterior of the House*
- ○ *In the House - Problem Did Not Exist Before*
  (Please Describe) _____
  _____
- ○ *In the House - Problem is Now Worse*
  (Please Describe) _____
  _____
- ○ *Other (Please Describe)* _____
  _____

Furnace Shutdown Due To (Use a number to indicate more than one occurence)

- ○ *Ice Blocking Exhaust Hood or Cap for Chimney/Flue*
- ○ *Mechanical Failure (Specify Which Component)* _____
  _____
- ○ *Other (Please Describe)* _____

14. Which of the following problems have you experienced with the new furnace: (Con't)

Furnace Noise (Check both, if applicable)

- ○ Inside the House
- ○ Outside the House

Corrosion (Check both, if applicable)

- ○ Of the Flue
- ○ Of A Furnace Component (Specify) _____

Other Problems Not Listed Above (Specify Nature of Problem and Actions Taken to Resolve Problem - If more space is required, use an additional page) _____

_____

15. Have you found it difficult to find qualified servicepeople?

○ Yes ○ No

16. Have you ever experienced delays in servicing because parts were not available?

○ Yes ○ No

17. How much have you spent on repairs not covered by the warranty?

$_____

18. Compared to the old furnace, the new furnace has made your home:

- ○ Less Comfortable
- ○ About the Same in Comfort
- ○ More Comfortable

19. When was your home built?

- ○ Before 1945
- ○ 1945 - 1960
- ○ 1961 - 1975
- ○ After 1975

20. How many storeys does your home have?

- ○ One Storey
- ○ One & Half Storey
- ○ Two Storey
- ○ Two & Half Storey
- ○ Three Storey
- ○ Split Level
- ○ Split Entry (Bi-Level)

21. What is the approximate floor area of your home?
(Do not include the basement)

- ○ Less than 1000 square feet
- ○ 1000 to 1500
- ○ 1500 to 2000
- ○ More than 2000

22. What year did you move into your home? (Please also indicate month, if possible.)

_____

23. Has the number of people living in your home changed within the last five years? (If yes, please state whether number increased or decreased and when the change occurred)
(e.g. Baby arrived June/84)

- ○ Yes _____
- ○ No

24. Please indicate thermostat settings used with both the old and new furnace:

Old Furnace

- Usual Thermostat Setting _____ Degrees
- Setback (If Applicable) _____ Degrees for _____ hours per day

New Furnace

- Usual Thermostat Setting _____ Degrees
- Setback (If Applicable) _____ Degrees for _____ hours per day

25. Do you use a woodstove, fireplace, electric heater, kerosene heater or other device to supplement the heat provided by the furnace?
(If yes, please describe and indicate usage over past five years.)
(e.g. Woodstove in basement, installed May/83, used one evening a week during winter.)
(e.g. Portable electric heater in TV room, purchased Nov/85, used daily Nov/85 to Mar/86 but not after new furnace installed.)

- ○ Yes _____
  _____
- ○ No

26. *Have you added, removed or replaced any of the following appliances within the last five years? (If yes, please state when equipment was added, removed or replaced)*
(e.g. Replaced electric hot water tank with natural gas tank in March/86.)

- ○ *Electric or Natural Gas Hot Water Tank* _____
- ○ *Natural Gas Stove, Cooktop, Wall Oven or Barbeque* _____
- ○ *Natural Gas Fireplace* _____
- ○ *Natural Gas Swimming Pool Heater* _____
- ○ *Other Natural Gas Appliances* _____

27. *Have you made any of the following changes to your home within the last five years? (Please check as many as apply and briefly describe what was done and when it is was done.)*
(e.g. New Vinyl Siding over 1" of styrofoam in May/86)

- ○ *Insulated Basement, Attic or Walls* _____
- ○ *Replaced Windows and/or Doors* _____
- ○ *Added Caulking and Weatherstripping* _____
- ○ *Enlarged Size of Home* _____
- ○ *Added or Replaced Exhaust Fans* _____
- ○ *Added or Replaced A Major Electrical Appliance* _____

- THANK YOU FOR YOUR ASSISTANCE -

PLEASE MAIL THE COMPLETED PERMISSION FORM AND QUESTIONNAIRE IN THE ENCLOSED POSTAGE PAID ENVELOPE. YOUR COOPERATION IN THIS STUDY IS GRATEFULLY APPRECIATED.

APPENDIX B

COMFORT LEVELS AND HIGHER-EFFICIENCY GAS HEATING SYSTEMS

One of the questions asked in the survey of higher-efficiency furnace and boiler owners was "Compared to the old furnace (boiler), the new furnace (boiler) has made your home: less comfortable, more comfortable, or about the same in comfort?". Guidance on the definition of comfort was not provided. A context-relevant meaning may be derivable from the more than 300 responses to the question. This could be important to the analysis of energy savings because it has been suggested that actual energy savings due to conservation measures may be lower for the older homes which would be starting further away from modern standards of thermal resistance and airtightness. Occupants of these homes may extract some of the benefits of the work in the form of comfort due to facilitated higher interior temperatures, lower expenditure for energy, etc. This would reduce their fuel savings.

The common element in the study group is a new mid- or high-efficiency furnace or boiler installation after mid-1985. The winter of 1986-87 was unusually warm; that of 1987-88 up to the time of answering the comfort question was also mild. The types of people making up the sample have been profiled in Section 5.1. Responses to the comfort question are detailed in Table B.1.

Very few indicated that their homes were less comfortable. Those who did were quite specific about the reasons. As an example, in one case where the old humidifier had not been replaced along with the furnace, dryness of the interior air was cited as a problem. In another, an allergy to ozone generated by a new electronic air cleaner had become a problem.

Almost all respondents reported that their homes were either more comfortable or about the same, and both groups were well represented throughout the sample. A comfort improvement was more common in the older houses and in the smaller houses. The positive impact on reported comfort was greater in houses in which high-efficiency furnaces had been installed compared to those with mid-efficiency furnaces.

The homeowners were also asked to indicate the thermostat settings used with both the old and new heating plants, including setback settings and lengths of time at the various settings. For many, installation of the new furnace or boiler included replacement of the old thermostat with a new setback type. Many made use of the setback feature and others did not. Some had been manually reducing the thermostat settings for part of the day and continued to do so with the new furnace and old thermostat. In some cases a new manually operated thermostat was installed. In others, the old thermostat was retained and no setbacks were used.

In addition to the many before-and-after combinations of thermostats and usage, there was a range of approximately 6 degrees (C) in the normal thermostat settings reported by the respondents. Personal preference and state of calibration of the thermostats both may have had something to do with the reported range of settings. For study purposes, a weighted-average temperature setback for each house was calculated from the numbers of hours

per week at the regular setting and at each temperature setting below the regular setting.

For mid- and high-efficiency furnaces only, Figures B.1 and B.2 summarize the changes to the reported temperature settings from the pre-replacement period to the period with the new furnaces, and illustrate the relationships between temperature settings and comfort changes. Interpretation of the figures may be made as follows, using as an example the subgroup of all mid-efficiency furnaces with comfort the same as with the old furnace (left-most bars of Figures B.1 and B.2).

Figure B.1 shows that, compared to the pre-replacement period, 23.2 % of respondents in this group used a lower thermostat setting during the non-setback hours, 74.4 % reported thermostat settings the same in the "before" and "after" periods, and 2.4 % stated post-replacement settings which were higher.

Figure B.2 indicates that, for the normal thermostat setting, there was an average reduction reported by the mid-efficiency/same-comfort group of 0.24 degrees (C) in going from the "before" period to the "after" period. In addition to this there was an increased use of temperature setbacks, the time-averaged value (over the week) of which was 0.13 degrees for the whole group. The net effect was an equivalent thermostat adjustment of 0.37 degrees (downward).

When compared for all groups, the results shown in Figures B.1 and B.2 are dramatic: a perception of greater comfort with the new heating plant is accompanied by a decrease in temperature settings.

All groups reported greater use of setbacks (combination of the amount of setback and the lengths of time set back) after their new furnaces were in operation. This is to be expected, given the awareness generated through the furnace replacement exercise and the placing into service of more automatic setback thermostats. However, those who reported greater comfort also made consistently greater increases in their use of setbacks compared to their counterparts who reported no change in comfort, as follows:

Change in Time-Averaged Setback Usage, by Group

Furnace type Comfort: after vs. before	mid same	mid more	high same	high more
Pre-replacement setback (C)	0.38	0.34	0.35	0.37
Post-replacement setback (C)	0.51	0.70	0.52	0.71
Equivalent t'stat change (C)	-0.13	-0.36	-0.17	-0.34

The increased setback is shown as the unfilled portion of the bars in Figure B.2. The "more-comfort" groups' increased use of setback was about twice that of the "same-comfort" groups. This difference was also greater for the older homes compared to the newer ones.

During the times when people were using the heated space (i.e., at home and awake), and had the thermostats set at higher values, a consistently greater proportion of those settings were lower than with the old furnace for homeowners reporting greater comfort (Figure B.1). Changes in the average normal thermostat settings for the four main groups were as follows:

Change in Non-Setback Thermostat Setting, by Group

Furnace type	mid	mid	high	high
Comfort: after vs. before	same	more	same	more
Change in normal setting (C)	-0.24	-0.72	+0.08	-0.63

These values are also shown in Figure B.2. Average temperature settings did not change very much where comfort was reported to be the same. However, "more comfortable" meant a reduction of between about 0.5 and 0.8 degrees in all subgroups, with the smaller reductions in the older houses.

The net effective change in reported thermostat setting is thus distributed as follows:

Net Change in Thermostat Setting, by Group

Furnace type	mid	mid	high	high
Comfort: after vs. before	same	more	same	more
Change in net setting (C)	-0.37	-1.08	-0.10	-0.97

Where comfort level was reported to be relatively unchanged, a slight reduction in net thermostat setting was reported. Where comfort level was reported to have improved, there was a group-averaged effective reduction in thermostat setting of approximately one degree (C).

TABLE B.1 REPORTED CHANGE IN COMFORT LEVEL DUE TO NEW FURNACE OR BOILER

Subgroup	No.	Percentage of Total in Subgroup			
		No Answer	Less	Same Comfort	More
Mid-Efficiency Furnaces					
pre-1945	38	5.3	-	31.6	63.2
1945-60	83	1.2	1.2	47.0	50.6
1961-75	59	3.4	1.7	54.2	40.7
post-1975	-	-	-	-	-
< 93 m²	51	5.9	2.0	37.3	54.9
93-139	115	1.7	0.9	48.7	48.7
139-186	11	-	-	45.5	54.5
>186 m²	3	-	-	100.0	-
all mid	180	2.8	1.1	46.1	50.0
High-Efficiency Furnaces					
pre-1945	24	-	-	33.3	66.7
1945-60	65	1.5	3.1	36.9	58.5
1961-75	39	-	5.1	41.0	53.8
post-1975	1	-	-	-	100.0
< 93 m²	32	3.1	-	34.4	62.5
93-139	80	-	5.0	33.8	61.3
139-186	14	-	-	64.3	35.7
>186 m²	3	-	-	33.3	66.7
all high	129	0.8	3.1	37.2	58.9
Upgraded Conventional Furnaces					
all upgr. conv.	8	-	-	62.5	37.5
Higher-Efficiency Boilers					
pre-1945	5	-	-	20.0	80.0
1945-60	4	-	-	50.0	50.0
< 93 m²	1	-	-	-	100.0
93-139	2	-	-	-	100.0
139-186	3	-	-	66.7	33.3
>186 m²	3	-	-	33.3	66.7
all boilers	9	-	-	33.3	66.7

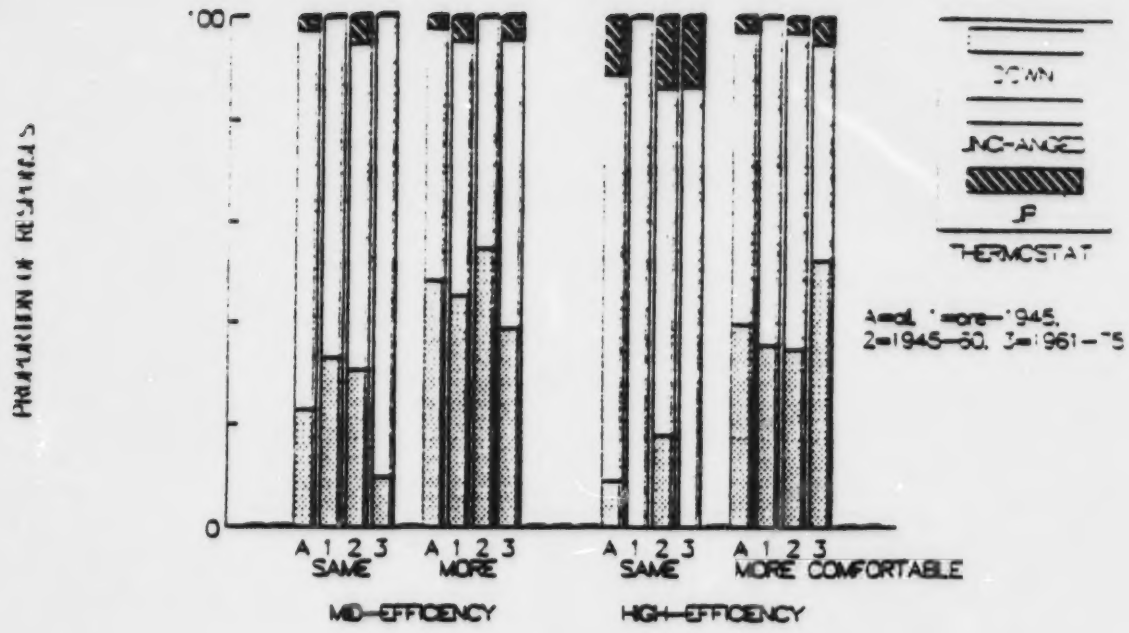

Figure B.1 Impact of Mid- and High-Efficiency Forced Air Furnaces on Comfort Levels and Reported Normal Thermostat Settings

Figure B.2 Impact of Mid- and High-Efficiency Forced Air Furnaces on Comfort Levels and Average Changes in Net Reported Thermostat Settings

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APPENDIX C

SUPPLEMENTARY STUDY OF REPLACEMENT CONVENTIONAL FURNACES AND BOILERS

September 1989

UNIES Ltd.

TABLE OF CONTENTS

Section		Page
C.1	INTRODUCTION	C.1
C.2	METHODOLOGY	C.1
C.2.1	Sample Selection	C.1
C.2.2	Analysis of Energy Consumption	C.2
C.2.3	Furnace and Boiler Types Represented in the Supplementary Sample	C.2
C.3	SAMPLE CHARACTERISTICS	C.2
C.3.1	House Profile	C.2
C.3.2	Occupant Profile	C.3
C.3.3	Gas Usage Characteristics	C.3
C.4	ENERGY SAVINGS ANALYSIS	C.6
C.4.1	Domestic Water Heating	C.6
C.4.2	Gas Savings	C.6
C.4.3	Possible Factors Affecting the Energy Savings	C.11
C.4.4	Comfort Levels and Temperature Settings	C.15
C.5	HOMEOWNER EXPERIENCES	C.18
C.5.1	Selection of the New Furnaces and Boilers	C.18
C.5.2	Problem Areas	C.18
C.6	SUMMARY OF RESULTS	C.25

LIST OF FIGURES

Figure		Page
C.1	Composition of House Sample for Conventional Furnace and Boiler Replacements	C.4
C.2	Comparison of Higher-Efficiency and Conventional House Sample Characteristics: Length of Occupancy	C.5
C.3	Heating Fuel Usage Characteristics of Conventional Furnace and Boiler Replacement Sample	C.5
C.4	Approximate Annual Natural Gas Consumption by Domestic Water Heaters in 34 Homes in which a Conventional Furnace or Boiler was Installed as a Replacement	C.8
C.5	Effect of Replacement Conventional Furnace on Annual Natural Gas Usage	C.9
C.6	Effect of Replacement Upgraded Conventional Furnaces on Annual Natural Gas Usage	C.10
C.7	Effect of House Type on Fuel Savings with Conventional Furnaces	C.12
C.8	Effect of House Age on Fuel Savings with Conventional Furnaces	C.12
C.9	Effect of Furnace Fan Operation on Fuel Savings with Conventional Furnaces	C.13
C.10	Effect of Comfort Change on Fuel Savings with Conventional Furnaces	C.13
C.11	Effect of Other Changes on Fuel Savings with Conventional Furnaces	C.14
C.12	Impact of New Conventional Furnaces and Furnace Fan Operation on Comfort Levels and Reported Normal Thermostat Settings	C.17
C.13	Impact of New Conventional Furnaces and Furnace Fan Operation on Comfort Levels and Average Changes in Net Reported Thermostat Settings	C.17
C.14	Reasons for Furnace or Boiler Replacement where Conventional Units were Installed	C.19
C.15	Types and Ages of Replaced Heating Plants where Conventional Units were Installed	C.20

LIST OF FIGURES (continued)

Figure		Page
C.16	Number of Quotations Obtained Prior to Selection of New Conventional Furance or Boiler	C.21
C.17	Reasons for Choice of Make or Model where Conventional Units were Installed	C.22
C.18	Distribution of Non-Routine Service Visits for Conventional Replacement Furnaces or Boilers	C.23
C.19	Reported Problems Involving Expense for Conventional Replacement Furnaces and Boilers	C.23
C.20	Types of Problems Noted by Homeowners Who Received Non-Routine Service Visits for Replacement Conventional Furnaces or Boilers	C.24

LIST OF TABLES

Table		Page
C.1	Fuel Savings Summary - Conventional and Higher-Efficiency Space Heating Equipment	C.7
C.2	Reported Change in Comfort Level Due to New Furnace or Boiler	C.16

APPENDIX C

SUPPLEMENTARY STUDY OF REPLACEMENT CONVENTIONAL FURNACES AND BOILERS

C.1 INTRODUCTION

In light of the wide ranges of expected percentage savings which were found to arise when conventional space heating furnaces and boilers were replaced with higher-efficiency units, a similar group of standard furnace and boiler replacements from the same time period was examined. The objectives of this supplementary study were to determine the corresponding ranges of savings likely to occur when the old naturally aspirated units with continuous pilot are exchanged for new naturally aspirated ones, and thereby to provide a firm picture of the relative changes to be expected from the choices of standard, upgraded conventional, mid-efficiency, and high-efficiency equipment.

C.2 METHODOLOGY

C.2.1 Sample Selection

Manitoba Department of Labour gas permit records were used to identify 294 Winnipeg-area homes in which natural gas furnaces or boilers were replaced with new naturally aspirated units in the interval between mid-September 1985 and mid-October 1986. The bulk of the supplementary sample originates from the period April to September 1986. Included were 252 furnaces and 42 boilers.

As done in the case of the higher-efficiency furnace and boiler replacements described in the main body of this report, a consent and utility release form and brief questionnaire package was sent to the homeowners in the sample. Questions from the earlier survey (Appendix A) which were only applicable to higher-efficiency equipment were replaced in the supplementary survey with questions about pilot light and continuous circulation fan operation. The former was included as a check on the type of main burner ignition system (continuous pilot or spark), to clarify ambiguous gas permit information. The latter question was intended to be complementary to an examination of changes in electricity consumption patterns.

Fully completed questionnaires were received from 91 homeowners, representing 81 furnaces and 10 boilers. A number of the furnaces and one of the boilers turned out to be upgraded conventional units (intermittent pilot and automatic vent damper). Follow-up calls were made to some of the respondents to complete the information required for analysis. Two cases were excluded from further study because they were conversions from oil to gas or from hot-water to forced-air systems.

From among the remaining 89 valid responses (80 furnaces, 9 boilers), there were 60 cases which appeared to be candidates for a before-and-after comparison of natural gas usage, and these were selected for utility record analysis.

C.2.2 Analysis of Energy Consumption

The methods described in Section 4.2 for relating energy consumption and outdoor temperature were applied to the meter reading histories for the 60 supplementary study houses. The gas and electricity records used in the analysis were compiled with the assistance of ICG Utilities and Manitoba Hydro. Cases with ambiguous, sparse, or trending consumption patterns were discarded from further consideration, leaving a final group of 50 for comparison of weather-normalized gas usage before and after replacement of the furnace or boiler.

C.2.3 Furnace and Boiler Types Represented in the Supplementary Sample

Within the various furnace and boiler categories in the final sample of 50 analyzed cases, the following manufacturers were represented:

(a) 38 naturally aspirated standing-pilot forced air furnaces: Climate Master, Ducmatic Olsen, ICG/Keeprite, Lennox

(b) 8 upgraded conventional forced air furnaces (intermittent pilot and automatic vent damper): ICG/Keeprite, Lennox

(c) 4 naturally aspirated standing-pilot hot water boilers: Slant/Fin, Weil-McLain

C.3 SAMPLE CHARACTERISTICS

The fact that those surveyed for the higher-efficiency furnace and boiler energy savings study and this supplementary study of conventional furnaces and boilers elected to purchase different heating equipment means that the two groups are somehow different. As noted, the times of replacement also were clustered more around mid-1986 for the latter group, whereas the earlier survey drew more uniformly from the full one-year interval considered. However, as discussed below and shown in Figures C.1 to C.3, examination of the analyzed house samples for both groups shows that the houses and occupants included in the two responding samples appear to have no major dissimilarities which would invalidate a comparison study of the differences in energy savings attributable to heating system changes in the two groups.

C.3.1 House Profile

Figure C.1(a) shows the distribution of house types and ages in the supplementary sample (conventional replacement furnaces and boilers only). The overall proportion of houses in the various age categories is as follows, with the corresponding values from the main higher-efficiency sample group shown in parentheses: pre-1945, 42 % (21%); 1945-60, 37 % (49%); 1961-75, 21 % (30%). Responses for this supplementary study of standard furnaces and boilers came more from older houses.

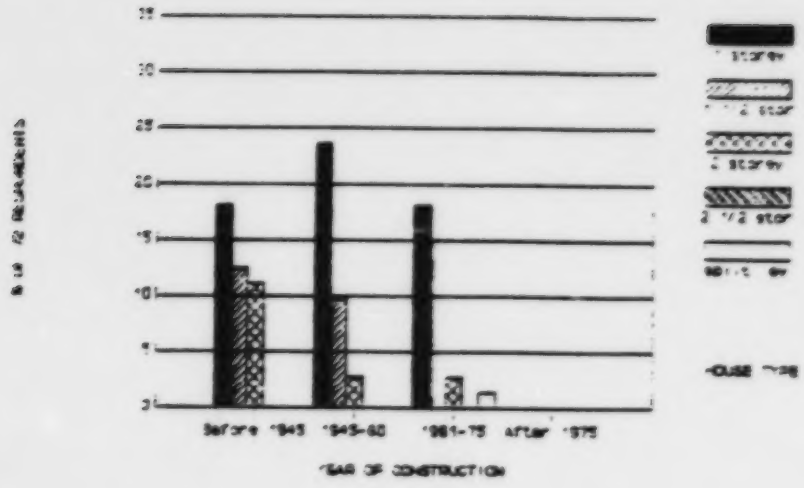
House size distribution is indicated in Figure C.1(b). Consistent with the above tendency toward older homes in the supplementary study, the proportion of responses from homes in the smallest-size category (under 93 m^2) was larger than it was for the higher-efficiency study respondents, and was about the same as that from the next larger size category (93 to 139 m^2).

C.3.2 Occupant Profile

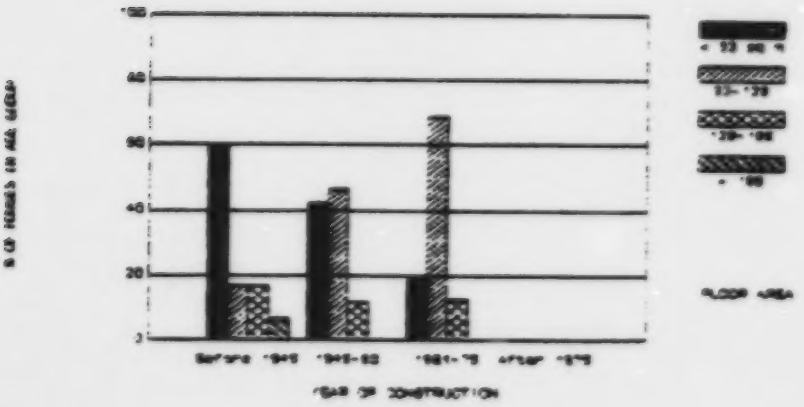
Length of occupancy for the supplementary sample group of homeowners (conventional units only) is illustrated in Figure C.2. Responses to the questionnaire indicate that, as with the higher-efficiency group, many of the people have been the only occupants of their homes and now these homes typically have low resident populations. As shown in the figure, there is a mild tendency for slightly longer occupancy periods to be characteristic of the supplementary sample. Generally the responses also show lower incidence of recent upgrading of energy related features in the houses. If upgrading work has been done in the last few years, it has tended to be related to windows, doors, and appliances.

C.3.3 Gas Usage Characteristics

Normalized natural gas usage totals for 42 houses (conventional units only) for which meter reading analysis was completed are shown in Figure C.3. The ranges in each age category are similar for this group and the higher-efficiency sample (Figure 5.3), but the total gas consumption is lower for the conventional replacement cases, probably reflective of the above-noted tendency toward smaller houses in the group.



(a)



(b)

Figure C.1 Composition of House Sample for Conventional Furnace and Boiler Replacements: (a) House age and type, (b) House age and size (note: 93 m^2 = 1000 square feet, nominal area).

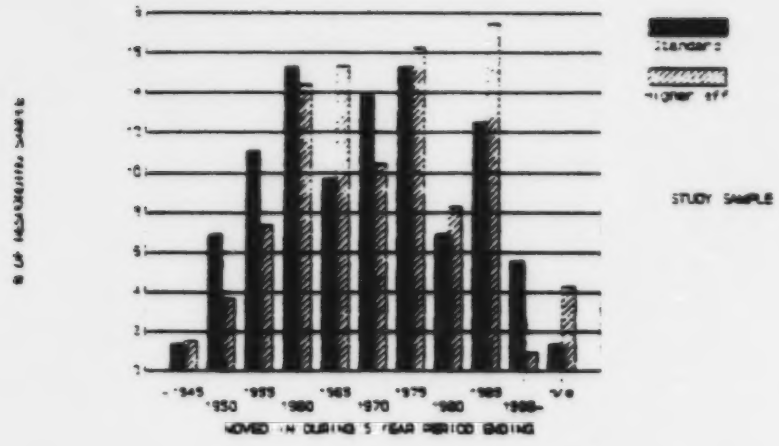


Figure C.2 Comparison of Higher-Efficiency and Conventional House Sample Characteristics: Length of Occupancy

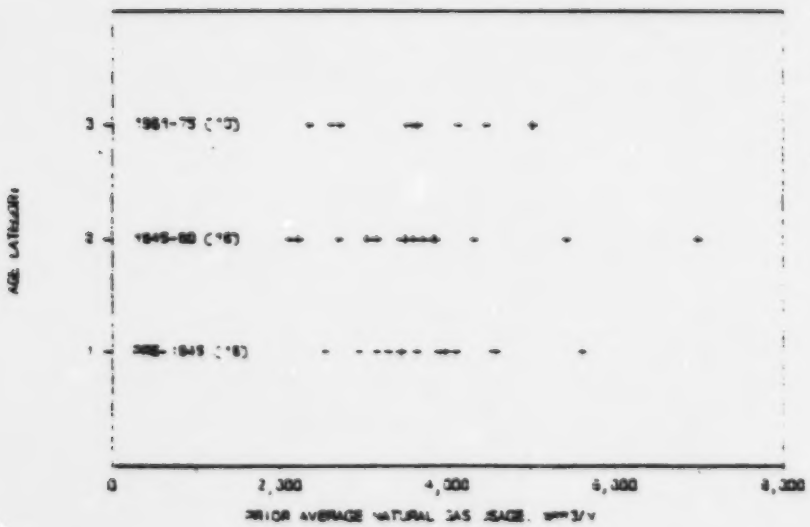


Figure C.3 Heating Fuel Usage Characteristics of Conventional Furnace and Boiler Replacement Sample

C.4 ENERGY SAVINGS ANALYSIS

C.4.1 Domestic Water Heating

For 33 homes with gas DHW systems in the final analyzed sample, the approximated domestic water heating portions of the total normalized gas consumption are shown in Figure C.4. The average annual DHW portion is 674 m^3 and the average normalized annual total consumption is 3777 m^3, compared to 714 m^3 and 3919 m^3, respectively, for the higher-efficiency group.

C.4.2 Gas Savings

Fuel savings determined for the replacement standard and upgraded conventional furnace categories and the standard replacement boilers are shown in Figures C.5 and C.6, and in Table C.1.

Figures C.5(a) and C.6(a) refer to total gas savings in houses with gas DHW systems, while Figures C.5(b) and C.6(b) refer to the space heating consumption alone in houses with gas or electric DHW systems. The main study results for 6 upgraded conventional furnaces are included in Figure C.6, together with the 8 cases from the supplementary study. In Table C.1, the results shown in Figures C.5 and C.6 are summarized along with those for the analyzed cases in the conventional boiler category. The fuel savings for the various higher-efficiency categories examined in the earlier study are also included for comparison.

The ranges of savings for both the 14 total analyzed cases of upgraded conventional furnace replacements and the 38 standard furnace cases are similar to those found for mid- and high-efficiency units in the main study.

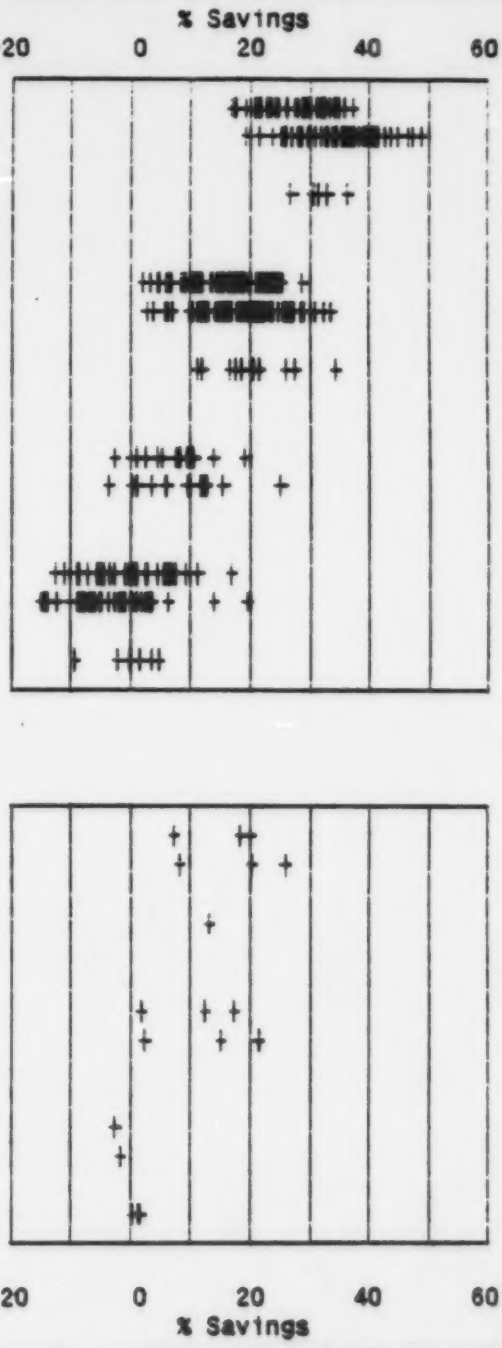
Total gas consumption decreased by an average of 6.9 % in the case of the upgraded conventional furnaces, with the average reduction estimated for the space heating portion of the gas usage being 8.5 %. The unusually high savings percentage shown for one of the houses can be largely attributed to elimination of the furnace pilot portion of a small total heating load.

The average consumption by new conventional furnaces and boilers was almost unchanged from that calculated for the units they replaced, reflecting the fact that the fundamental technology used to heat the sample houses was the same before and after the time of replacement. However, individual cases with changes in consumption exceeding ± 10 % were common in the test group. This magnitude of variation was also observed in the higher-efficiency study.

In all cases of houses involving gas DHW systems, characterization of the water heater consumption in order to allow estimation of the space heating gas usage means that some uncertainty is introduced into the results. Space heating savings levels presented in this report should therefore be used in full appreciation of this fact. In the case of the conventional furnace or boiler replacements, i.e., Figure C.5(b), it should be noted that the added uncertainty is greater than for the higher-efficiency categories because an assumed value for furnace pilot consumption rates for both the old and new furnaces has been used in the estimation of the space heating consumption (gas DHW houses). The value used in the calculation, 0.708 m^3/day or 25 ft^3/day, is consistent with average observed usage patterns; however, individual units actually may use significantly more or less than the adopted average value.

TABLE C.1 FUEL SAVINGS SUMMARY - CONVENTIONAL AND HIGHER-EFFICIENCY SPACE HEATING EQUIPMENT

Heating System	DHW	No.	Basis of Savings Calculation	Reduction in Normalized Annual Gas Consumption Average %
FURNACES				
High-efficiency	gas	49	Heat & DHW	27.5
			Heat only*	34.0
	elec	5	Heat only	31.5
Mid-efficiency	gas	66	Heat & DHW	15.8
			Heat only*	19.2
	elec	11	Heat only	20.5
Upgraded Conventional	gas	14	Heat & DHW	6.9
			Heat only*	8.5
Conventional	gas	32	Heat & DHW	0.4
			Heat only*	-2.7
	elec	6	Heat only	-0.3
BOILERS				
High-efficiency	gas	3	Heat & DHW	15.2
			Heat only*	18.1
	elec	1	Heat only	13.1
Upgraded Conventional	gas	3	Heat & DHW	10.5
			Heat only*	12.9
Conventional	gas	1	Heat & DHW	-2.6
			Heat only*	-1.7
	elec	3	Heat only	1.1



* Estimated by subtraction of estimated DHW gas usage from total gas usage.

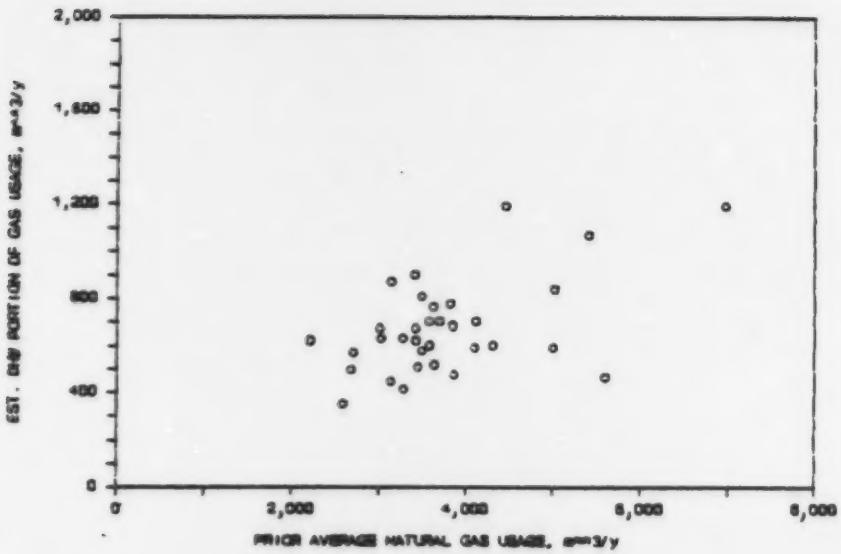
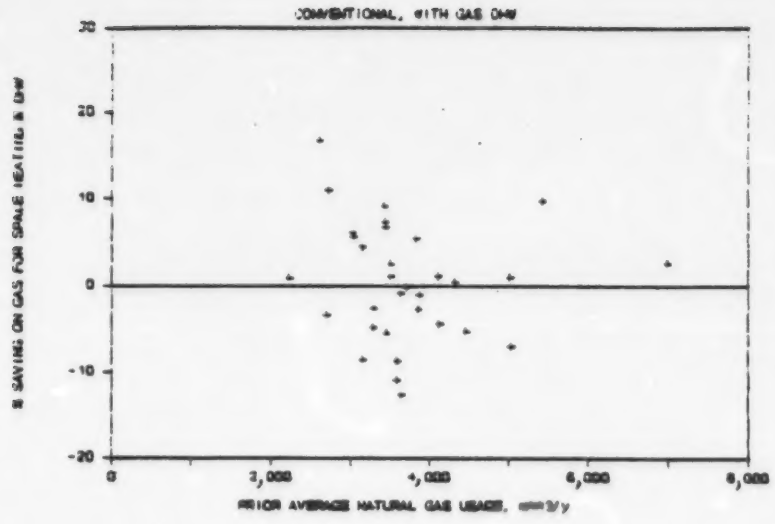


Figure C.4 Approximate Annual Natural Gas Consumption by Domestic Water Heaters in 33 Homes in which a Conventional Furnace or Boiler was Installed as a Replacement



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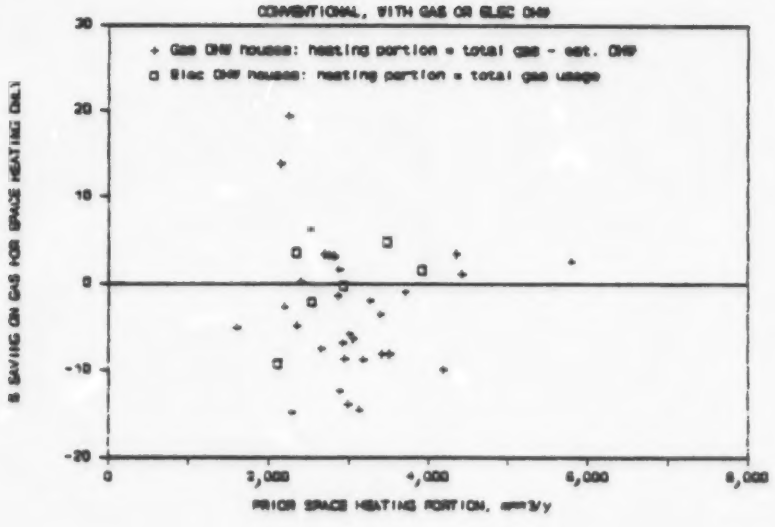
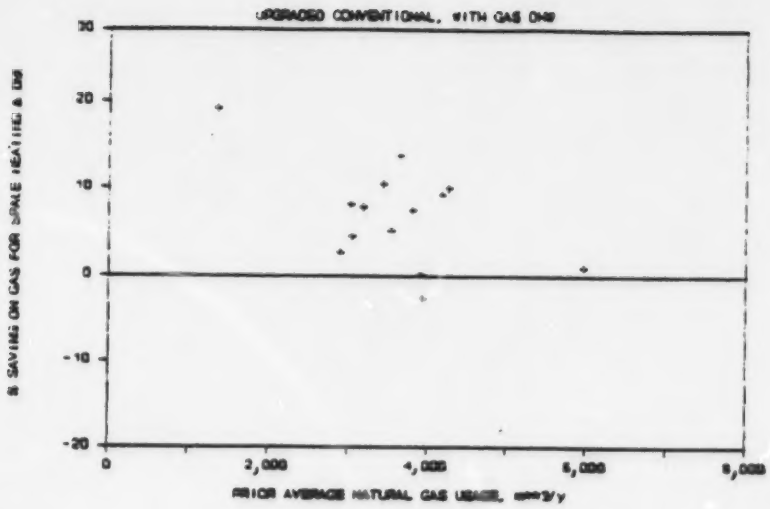


(b)

Figure C.5 Effect of Replacement Conventional Furnaces on Annual Natural Gas Usage: (a) Gas for Space Heating and DHW, (b) Space Heating Gas Only.



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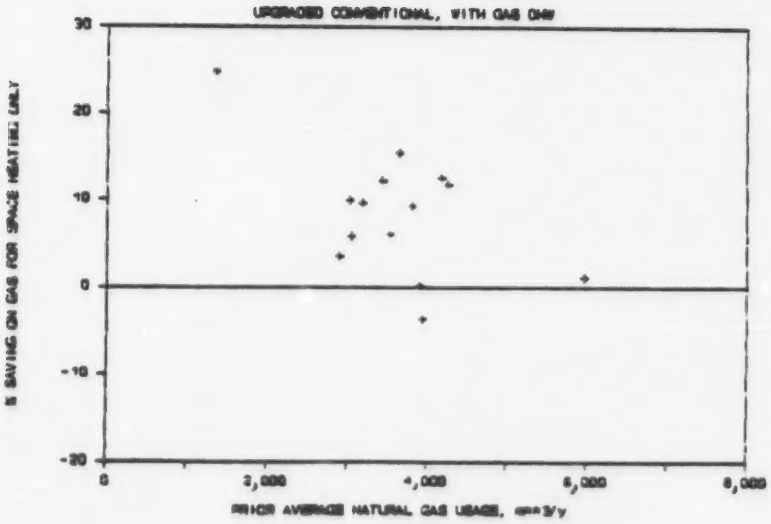


(b)

Figure C.6 Effect of Replacement Upgraded Conventional Furnaces on Annual Natural Gas Usage: (a) Gas for Space Heating and DHW, (b) Estimated Space Heating Gas Only.

C.4.3 Possible Factors Affecting the Energy Savings

Distributions of fuel savings subdivided according to house type, era of construction, use of a two-speed blower, comfort effect, and miscellaneous other mechanical system changes are shown in Figures C.7 through C.11. Except for the blower operation comparison, these are the same factors considered in the study of higher-efficiency replacements. Results for most of the groups are also similar, i.e., the ranges of savings are dominant, and the expected levels of savings would not be more closely predictable using the individual factors. Some of the specific findings are outlined below.

Among the cases where installation and use of a two-speed blower (i.e., "High/Low" in Figure C.9) was reported, some also exhibited the expected step increase in electricity consumption within the house. Where visible, steady usage attributable to a conversion to a mode of continuous operation of the furnace blower ranged from about 3.5 to 7 kWh/day, or 1000 to 2000 kWh for a 9-month heating season. However, the accompanying displacement of a portion of the space heating energy requirement for the houses involved does not appear as a noticeable influence within the natural gas savings results (refer to "More Electricity" in Figure C.11.

A weak relationship between perceived change in comfort and change in energy consumption may be suggested by the biases at the extremes of the distributions shown in Figure C.10, i.e., there are tendencies in the direction of both (a) a higher consumption and sense of greater comfort, and (b) a lower consumption and unchanged perception of comfort. However, a contrary tendency was also observed in the study and is discussed in the section following. An increased perception of comfort with the new furnace was found to be typically associated with a reduction in the normal temperature setting. This indicates that occupant-initiated changes in temperature settings also would not be useful in reducing the range within which energy consumption would be expected to be when a new conventional furnace was installed.

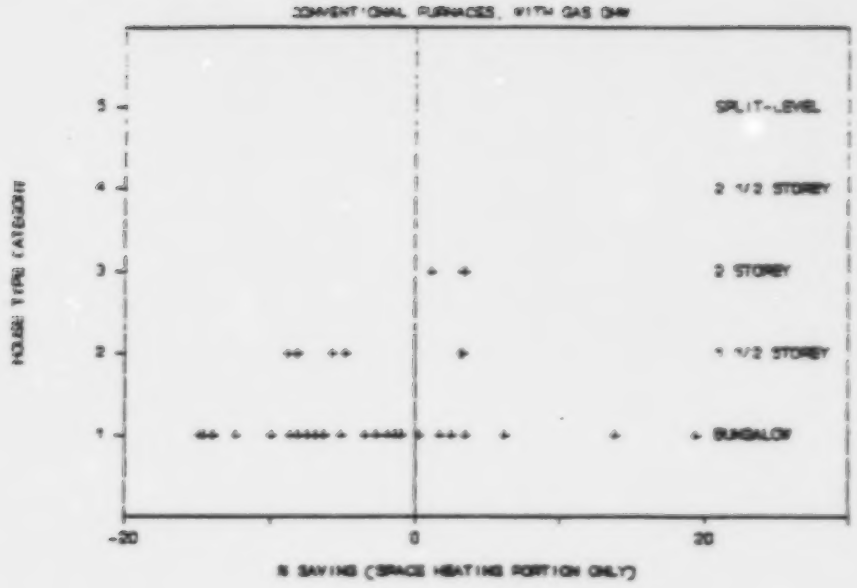


Figure C.7 Effect of House Type on Fuel Savings with Conventional Furnaces

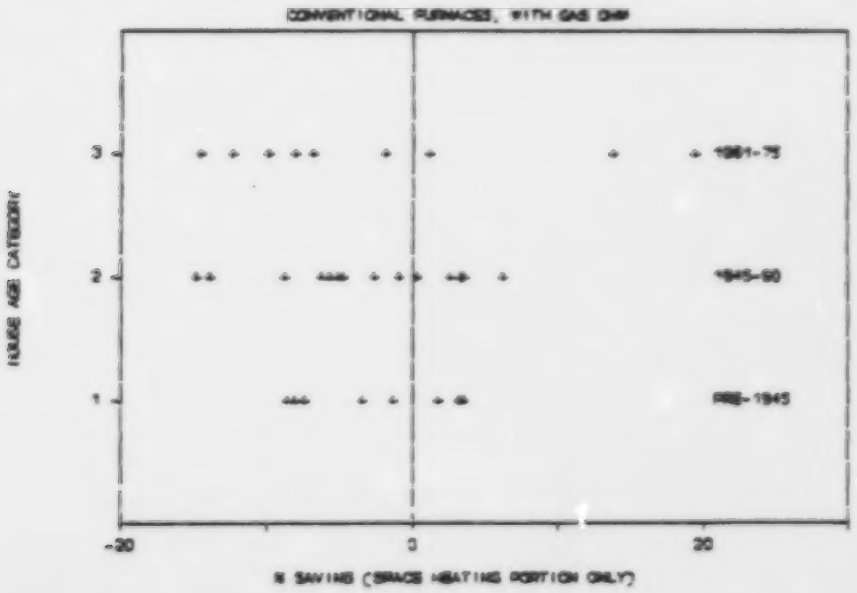


Figure C.8 Effect of House Age on Fuel Savings with Conventional Furnaces

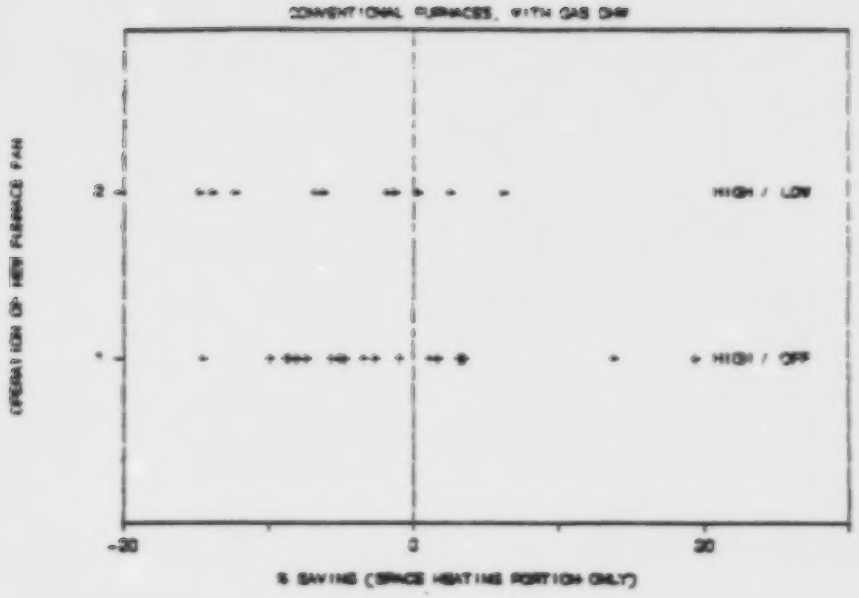


Figure C.9 Effect of Furnace Fan Operation on Fuel Savings with Conventional Furnaces

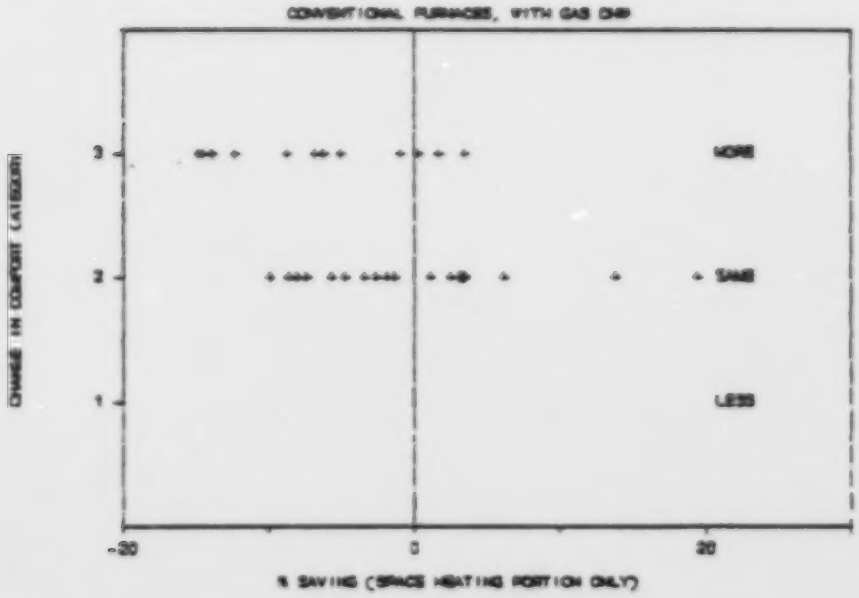


Figure C.10 Effect of Comfort Change on Fuel Savings with Conventional Furnaces

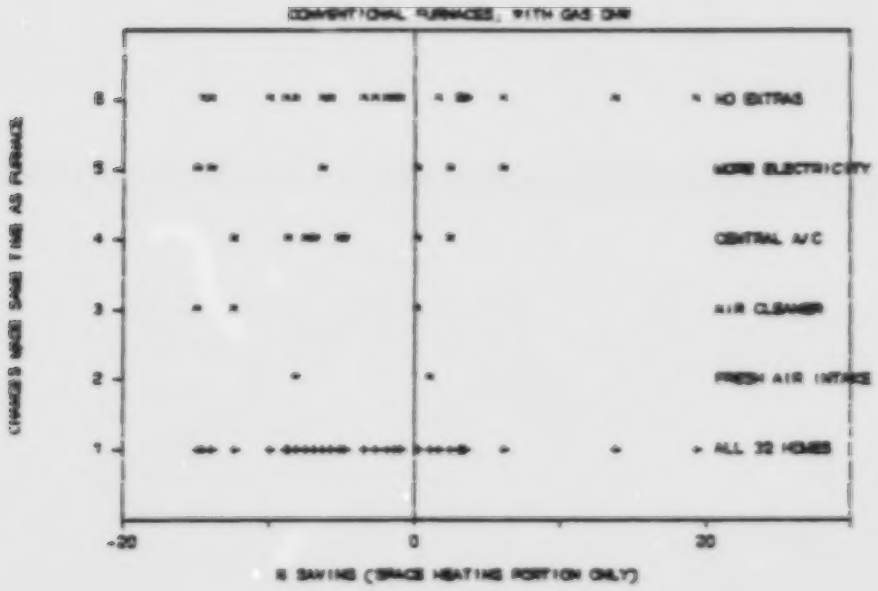


Figure C.11 Effect of Other Changes on Fuel Savings with Conventional Furnaces

C.4.4 Comfort Levels and Temperature Settings

An illustration of the relationships between the perceived comfort with the new conventional heating plants and the changes in thermostat settings made by people in the supplementary study group is given in Table C.2 and Figures C.12 and C.13. In summary:

Change in Time-Averaged Setback Usage, by Group

Furnace type	Conventional Standing Pilot			
Circulation fan usage	Discontinuous		Continuous	
Comfort: after vs. before	same	more	same	more
Sample size	28	15	8	9
Pre-replacement setback (C)	0.25	0.26	0.36	0.08
Post-replacement setback (C)	0.33	0.29	0.29	0.08
Equivalent t'stat change (C)	-0.08	-0.03	+0.07	0.00

Change in Non-Setback Thermostat Setting, by Group

Change in normal setting (C)	-0.15	-0.61	-0.36	-0.43

Net Change in Thermostat Setting, by Group

Change in net setting (C)	-0.23	-0.64	-0.29	-0.43

Setback usage did not change much when the old standard furnaces were replaced with new standard units, nor were changes in setback usage associated with perceived changes in comfort level with the furnace replacement. As with the higher-efficiency replacements, however, temperature settings during non-setback periods were significantly lower than they were prior to furnace replacement if the occupants also felt that their homes had been rendered more comfortable by the new furnaces (refer to Appendix B).

A number of the responding homeowners had opted for installation of capability for 2-speed blower operation along with their new standard furnaces, and reported that they ran their new fans continuously. For this group, there was little difference between the same- and more-comfortable houses in terms of changes to thermostat settings, indicating that there were factors other than temperature which affected their perception of comfort. A higher percentage of the homeowners with continuous circulation found that comfort level had improved with the new furnace. A comparison of these results with the higher-efficiency samples is not possible as questions about furnace fan usage were restricted to the supplementary study's questionnaire.

The net effective adjustment in thermostat setting with the new standard furnaces was a reduction of approximately 0.5 degrees (C) where comfort was thought to have improved (compares to about one degree for the higher-efficiency furnace replacements). For cases of unchanged apparent comfort level with a standard furnace replacement, the net reduction in temperature setting averaged lower (around 0.25 degrees), and was about the same as was observed for the similar group of higher-efficiency replacements.

The perceived effect of furnace replacement on the interior environment and the occupants' reaction to the change thus was found to be different for standard and higher-efficiency units. Generally, there was a greater impression of impact when a higher-efficiency furnace or boiler was installed in the home, a result which is consistent with the fundamental difference in nature of the equipment in comparison to the standard furnace.

TABLE C.2 REPORTED CHANGE IN COMFORT LEVEL DUE TO NEW FURNACE OR BOILER

Subgroup	No.	Percentage of Total in Subgroup			
		No Answer	Less	Same Comfort	More
Conventional Standing Pilot Furnaces - Discontinuous Circ. Fan Operation					
pre-1945	20	-	10.0	75.0	15.0
1945-60	15	-	6.7	40.0	53.3
1961-75	11	-	-	63.6	36.4
post-1975	-	-	-	-	-
< 93 m^2	30	-	3.3	70.0	26.7
93-139	12	-	-	50.0	50.0
139-186	4	-	50.0	25.0	25.0
>186 m^2	0	-	-	-	-
all w/o fan	46	-	6.5	60.9	32.6
Conventional Standing Pilot Furnaces - Continuous Circ. Fan Operation					
pre-1945	2	-	-	50.0	50.0
1945-60	10	-	-	50.0	50.0
1961-75	5	-	-	40.0	60.0
post-1975	-	-	-	-	-
< 93 m^2	2	-	-	-	100.0
93-139	12	-	-	41.7	58.3
139-186	2	-	-	100.0	-
>186 m^2	1	-	-	100.0	-
all with fan	17	-	-	47.1	52.9
Conventional Standing Pilot Boilers					
all std boilers	8	-	37.5	27.5	25.0

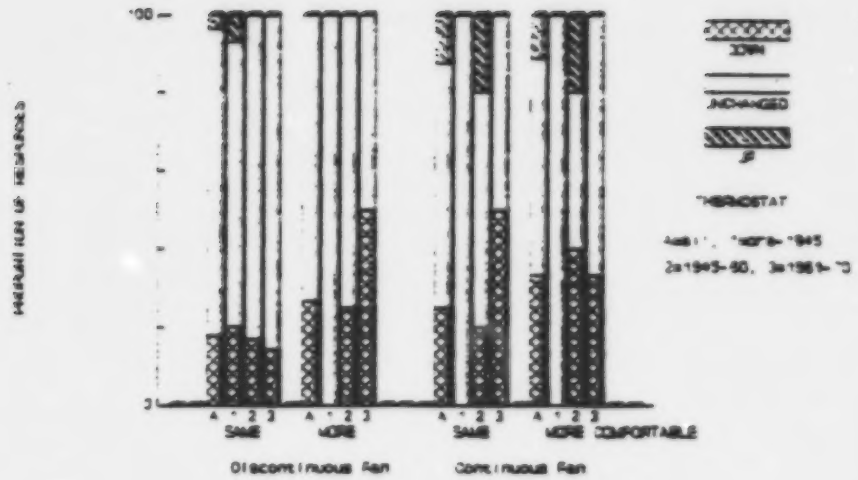


Figure C.12 Impact of New Conventional Furnaces and Furnace Fan Operation on Comfort Levels and Reported Normal Thermostat Settings

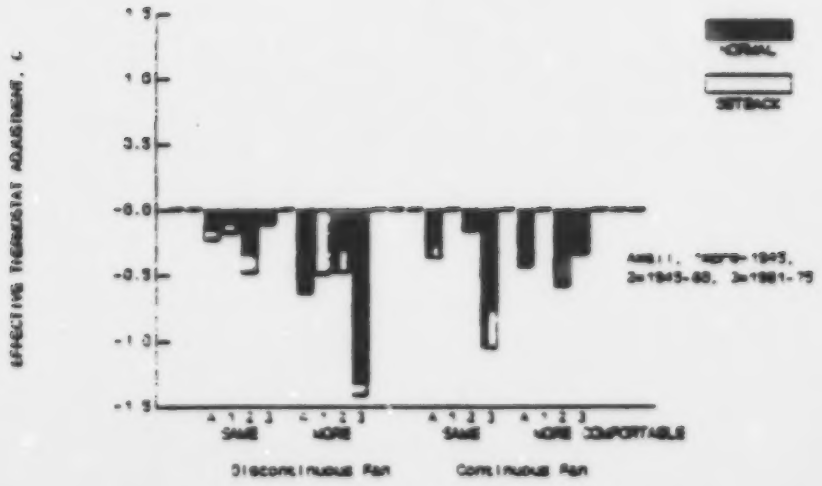


Figure C.13 Impact of New Conventional Furnaces and Furnace Fan Operation on Comfort Levels and Average Changes in Net Reported Thermostat Settings

C.5 HOMEOWNER EXPERIENCES

C.5.1 Selection of the New Furnaces and Boilers

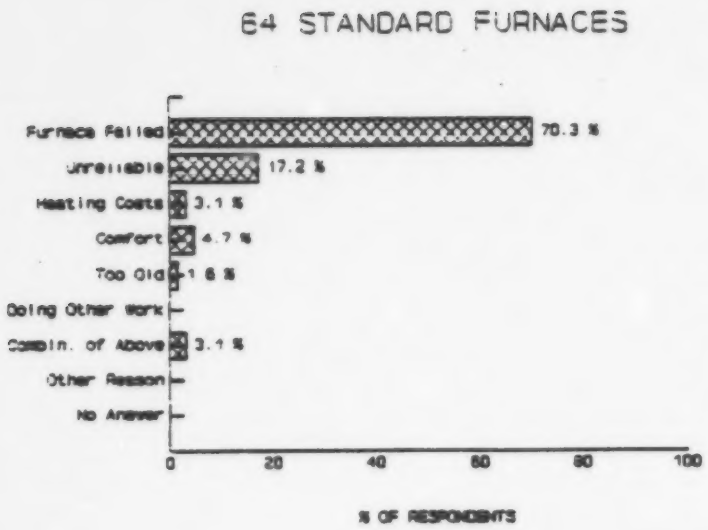
Figures C.14 to C.17 illustrate the reasons homeowners in the supplementary study gave for replacing their furnaces and boilers, the types and ages of the old units, the number of estimates obtained prior to installation, and the reasons for the final choices of unit. Some different trends are evident for this group in comparison to the earlier higher-efficiency study respondents.

In the supplementary group, for example, few of the replacements were completed for reasons other than failure of the existing units. The dominant age range for those replacements remained 20 to 30 years. Similarly, a larger proportion of homeowners acted on the basis of a single quotation to install a standard furnace or boiler, compared to those who purchased higher-efficiency equipment. Further, the heating contractor's recommendation, although showing similar dominance as the most important reason cited for choice of the unit actually installed in the home, became less important if the old unit had failed, contrary to the case for all the higher-efficiency subgroups. This drop in emphasis upon the contractor's advice was replaced mainly by the increased importance of the advice of friends, neighbours or relatives and price as deciding factors.

The above-noted effects are probably reflective of fundamental differences in lifestyles and experiences of groups of homeowners who made the choice of standard or higher-efficiency heating systems. The differences are not of large magnitude, however. As such, they suggest no reason to exclude comparison of energy savings between the two groups.

C.5.2 Problem Areas

Very few problems were reported with the new conventional furnaces from the time of installation (between September 1985 and October 1986) to March 1989, with one quarter of the respondents reporting a non-routine service visit (for the higher-efficiency equipment, the comparable fraction was about one third). In each case, the proportion of service calls was higher for the small boiler subgroup. The distribution of service visits is shown in Figure C.18, with the types of problems outlined in Figure C.20. Again, interruption of operation due to mechanical or electrical malfunction was the most common problem. In a few cases, the standing pilot went out. Repairs requiring expense by the homeowner tended to be less costly than those experienced by the higher-efficiency group, as shown in Figure C.19.



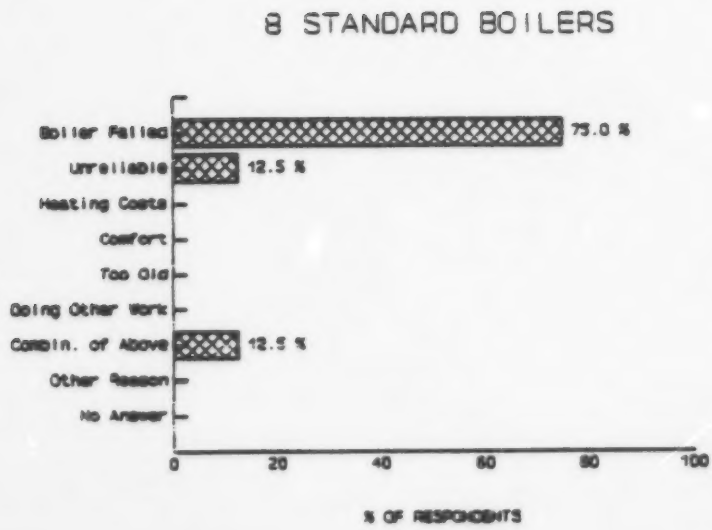
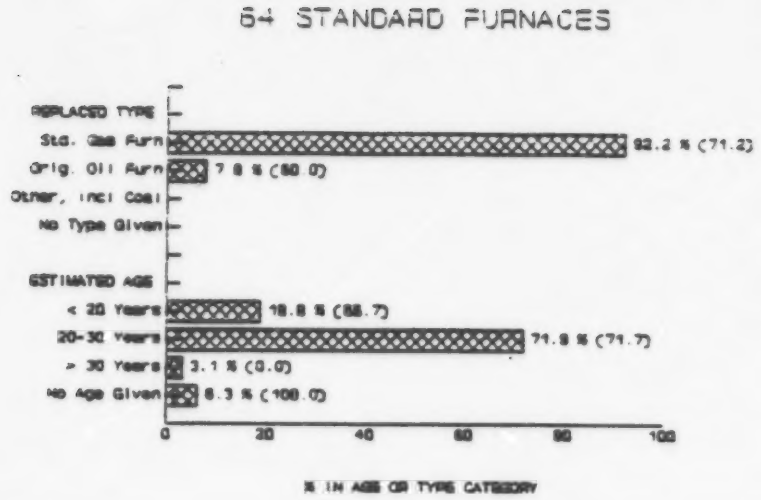


Figure C.14 Reasons for Furnace or Boiler Replacement where Conventional Units were Installed



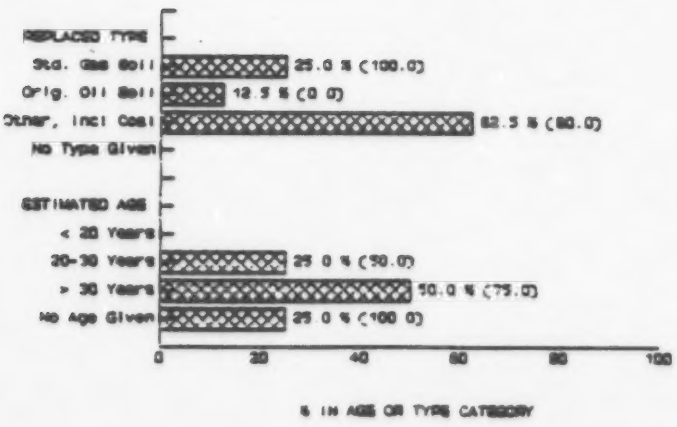


Figure C.15 Types and Ages of Replaced Heating Plants where Conventional Units were Installed (number in parentheses is percentage in the type or age category which were replaced due to failure).

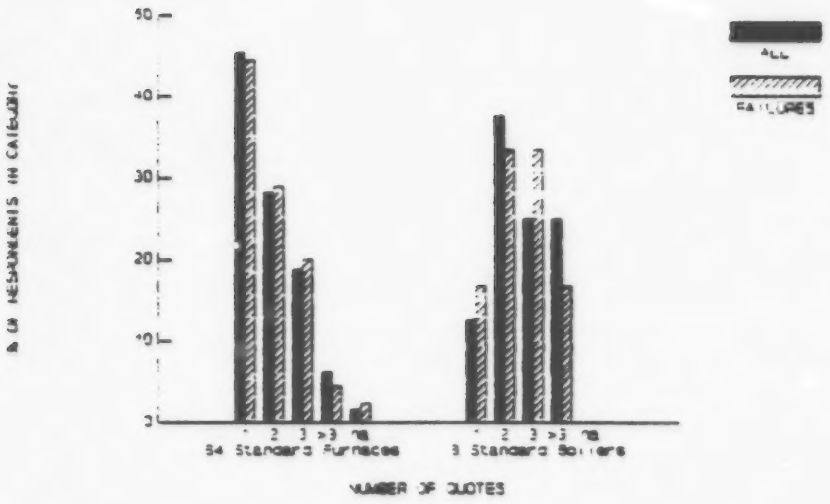


Figure C.16 Number of Quotations Obtained Prior to Selection of New Conventional Furnace or Boiler

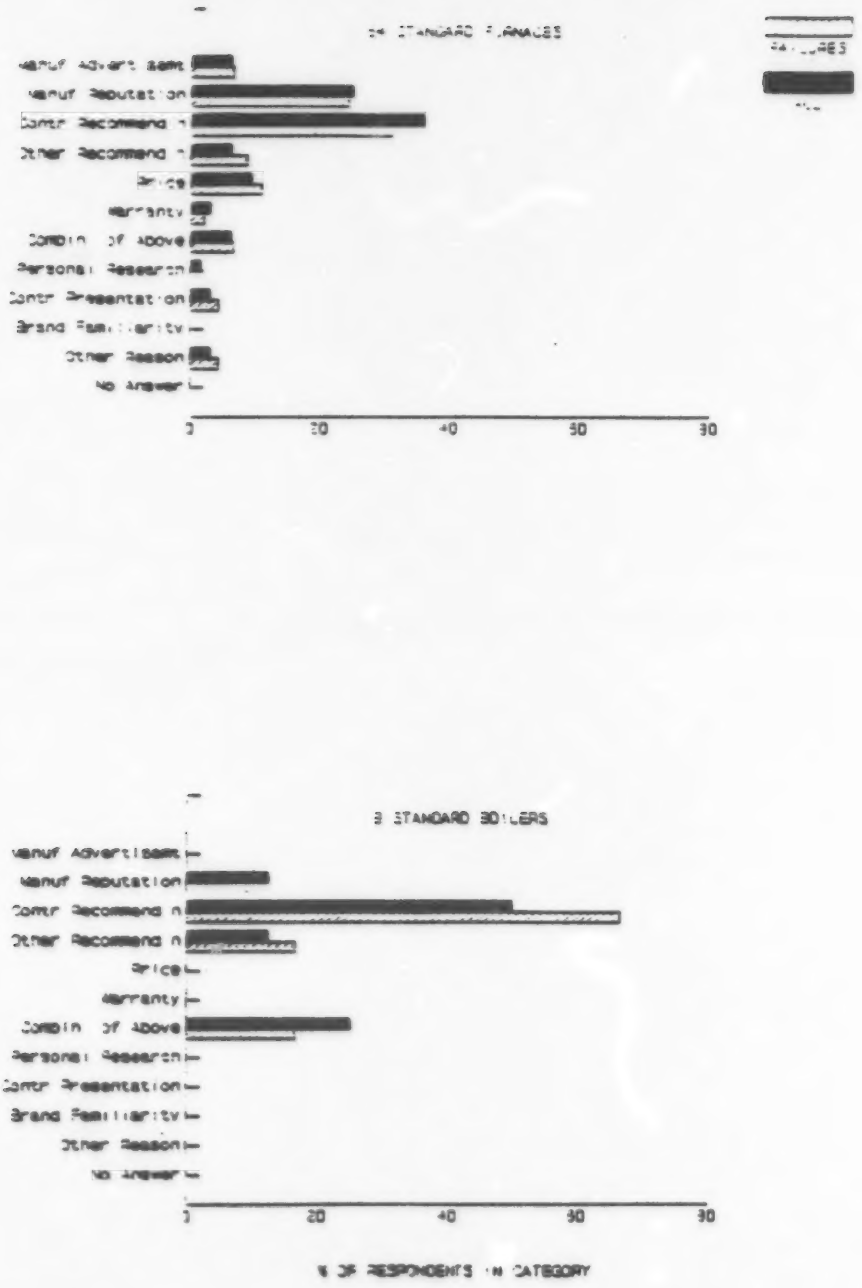


Figure C.17 Reasons for Choice of Make or Model where Conventional Units were Installed

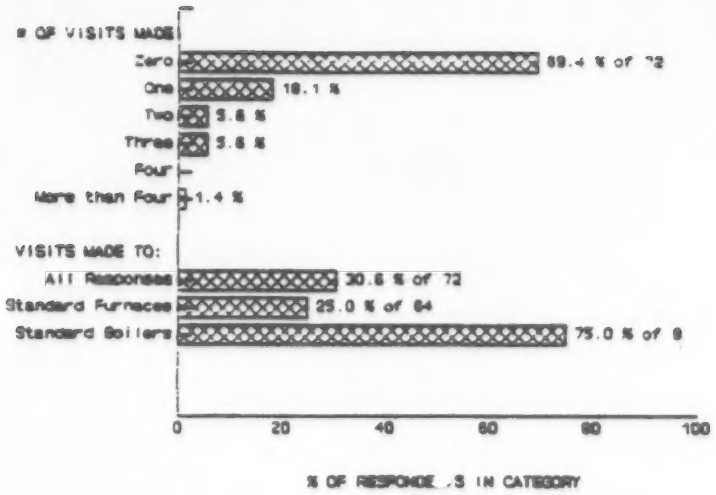


Figure C.18 Distribution of Non-Routine Service Visits for Conventional Replacement Furnaces or Boilers

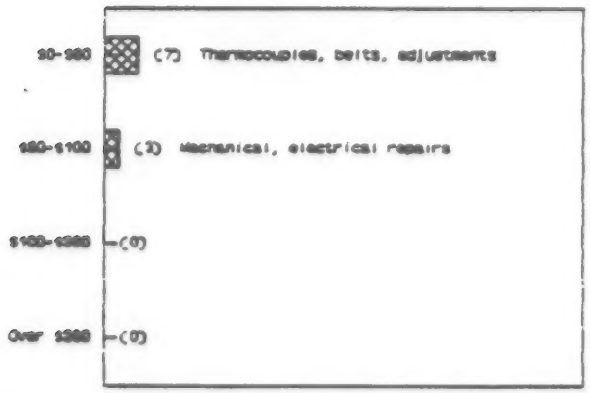


Figure C.19 Reported Problems Involving Expense for Conventional Replacement Furnaces and Boilers (number in parentheses is the number of occurrences in the expense category: sample size = 89).

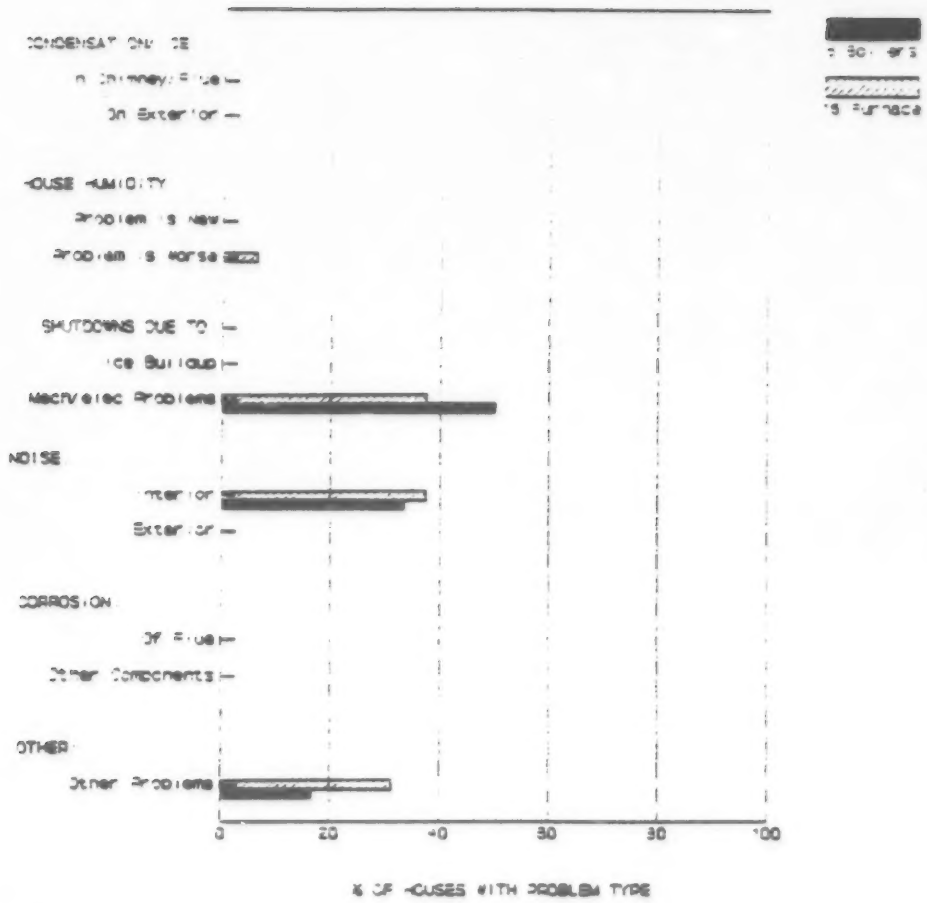


Figure C.20 Types of Problems Noted by Homeowners Who Received Non-Routine Service Visits for Replacement Conventional Furnaces or Boilers

C.6 SUMMARY OF RESULTS

Owners of 294 homes which had been retrofitted with conventional gas furnaces or boilers or upgraded conventional furnaces were requested to complete a questionnaire similar to that used for the higher-efficiency furnace and boiler study and they were also asked to grant project personnel access to the utilities' records of their energy consumption. Analysis of weather-normalized energy savings was completed for 50 houses out of the total of 89 valid responses.

The ranges of natural gas savings achieved in the sample of replacement conventional furnaces and the augmented sample of replacement upgraded conventional furnaces were of magnitude similar to those determined for higher-efficiency replacements:

(a) Sample homes with gas domestic water heaters and replacement conventional (standing pilot) furnaces saved an average of 0.4 % on the total annual gas consumption. For the estimated space heating portion of the total usage in the same houses, the average change was an increase of 2.7 %. For a small subsample of houses with electric domestic water heaters, the average change was an increase of 0.3 %.

(b) For a sample of upgraded conventional furnace installations including six from the earlier higher-efficiency results and eight from the supplementary study, the average saving on total gas usage was 6.9 %, and on the estimated space heating portion it was 8.5 %.

(c) The bands of savings above and below the averages for the two categories examined were on the order of 20 % or more, similar to the earlier findings for higher-efficiency replacements. The ranges were significantly greater than the apparent effects attributable to individual house, occupant, and operational differences.

(c) Where standard replacement units were installed, actual failure of the old heating plant was the reason for replacing the old furnace or boiler which was stated by 70 % of the homeowners surveyed. Also significant was a tendency toward fewer cost estimates being obtained prior to purchase of the new heating plant. Other trends in the responses were similar for both groups.

(d) Incidence of a requirement for adjustment or repair during the initial period after installation was slightly lower for the standard furnaces in the sample than for the higher-efficiency units in the main study, and where expenditure was required, it tended to be minor.